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(54) Title: EP4 RECEPTOR AGONIST, COMPOSITIONS AND METHODS THEREOF

(57) Abstract: This invention relates to potent selective agonists of the EP_4 subtype of prostaglandin E2 receptors, their use or a formulation thereof in the treatment of glaucoma and other conditions which are related to elevated intraocular pressure in the eye of a patient. This invention further relates to the use of the compounds of this invention for mediating the bone modeling and remodeling processes of the osteoblasts and osteoclasts.

EP_4 RECEPTOR AGONIST, COMPOSITIONS AND METHODS THEREOF

BACKGROUND OF THE INVENTION

Glaucoma is a degenerative disease of the eye wherein the intraocular pressure is too high to permit normal eye function. As a result, damage may occur to the optic nerve head and result in irreversible loss of visual function. If untreated, glaucoma may eventually lead to blindness. Ocular hypertension, i.e., the condition of elevated intraocular pressure without optic nerve head damage or characteristic glaucomatous visual field defects, is now believed by the majority of ophthalmologists to represent merely the earliest phase in the onset of glaucoma.

Many of the drugs formerly used to treat glaucoma proved unsatisfactory. Early methods of treating glaucoma employed pilocarpine and produced undesirable local effects that made this drug, though valuable, unsatisfactory as a first line drug. More recently, clinicians have noted that many β-adrenergic antagonists are effective in reducing intraocular pressure. While many of these agents are effective for this purpose, there exist some patients with whom this treatment is not effective or not sufficiently effective. Many of these agents also have other characteristics, e.g., membrane stabilizing activity, that become more apparent with increased doses and render them unacceptable for chronic ocular use and can also cause cardiovascular effects.

Agents referred to as carbonic anhydrase inhibitors decrease the formation of aqueous humor by inhibiting the enzyme carbonic anhydrase. While such carbonic anhydrase inhibitors are now used to treat elevated intraocular pressure by systemic and topical routes, current therapies using these agents, particularly those using systemic routes are still not without undesirable effects. Topically effective carbonic anhydrase inhibitors are disclosed in U.S. Patent Nos. 4,386,098; 4,416,890; 4,426,388; 4,668,697; 4,863,922; 4,797,413; 5,378,703, 5,240,923 and 5,153,192.

Prostaglandins and prostaglandin derivatives are also known to lower intraocular pressure. There are several prostaglandin types, including the A, B, C, D, E, F, G, I and J- Series (EP 0561073 A1). U.S. Patent 4,883,819 to Bito describes the use and synthesis of PGAs, PGBs and PGCs in reducing intraocular pressure. U.S. Patent 4,824,857 to Goh et al. describes the use and synthesis of PGD_2 and derivatives thereof in lowering intraocular pressure including derivatives wherein C-10 is replaced with nitrogen. U.S. Patent 5,001,153 to Ueno et al. describes the use

and synthesis of 13,14-dihydro-15-keto prostaglandins and prostaglandin derivatives to lower intraocular pressure. U.S. Patent 4,599,353 describes the use of eicosanoids and eicosanoid derivatives including prostaglandins and prostaglandin inhibitors in lowering intraocular pressure. See also WO 00/38667, WO 99/32441, WO 99/02165, WO 00/38663, WO 01/46140, EP 0855389, JP 2000-1472, US Patent No. 6,043,275 and WO 00/38690.

Prostaglandin and prostaglandin derivatives are known to lower intraocular pressure by increasing uveoscleral outflow. This is true for both the F type and A type of prostaglandins. This invention is particularly interested in those compounds that lower IOP via the uveoscleral outflow pathway and other mechanisms by which the E series prostaglandins (PGE_2) may facilitate IOP reduction. While the relationship between EP receptor activation and IOP lowering effects is not well understood, there are four recognized subtypes of the EP receptor (EP_1, EP_2, EP_3 and EP_4; *J. Lipid Mediators Cell Signaling*, Vol. 14, pages 83-87 (1996)). See also J. Ocular Pharmacology, Vol. 4, 1, pages 13-18 (1988); J. Ocular Pharmacology and Therapeutics, Vol. 11, 3, pages 447-454 (1995); J. Lipid Mediators, Vol. 6, pages 545-553 (1993); US Patent Nos. 5,698,598 and 5,462,968 and Investigative Ophthalmology and Visual Science, Vol. 31, 12, pages 2560-2567 (1990). Of particular interest to this invention are compounds, which are agonist of the EP_4 subtype receptor.

A problem with using prostaglandins or derivatives thereof to lower intraocular pressure is that these compounds often induce an initial increase in intraocular pressure, can change the color of eye pigmentation and cause proliferation of some tissues surrounding the eye.

As can be seen, there are several current therapies for treating glaucoma and elevated intraocular pressure, but the efficacy and the side effect profiles of these agents are not ideal. Therefore, there still exist the need for new and effective therapies with little or no side effects.

A variety of disorders in humans and other mammals involve or are associated with abnormal or excessive bone loss. Such disorders include, but are not limited to, osteoporosis, glucocorticoid induced osteoporosis, Paget's disease, abnormally increased bone turnover, periodontal disease, tooth loss, bone fractures, rheumatoid arthritis, periprosthetic osteolysis, osteogenesis imperfecta, metastatic bone disease, hypercalcemia of malignancy, and multiple myeloma. One of the most common of these disorders is osteoporosis, which in its most frequent manifestation

occurs in postmenopausal women. Osteoporosis is a systemic skeletal disease characterized by a low bone mass and microarchitectural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture. Osteoporotic fractures are a major cause of morbidity and mortality in the elderly population. As many as 50% of women and a third of men will experience an osteoporotic fracture. A large segment of the older population already has low bone density and a high risk of fractures. There is a significant need to both prevent and treat osteoporosis and other conditions associated with bone resorption. Because osteoporosis, as well as other disorders associated with bone loss, are generally chronic conditions, it is believed that appropriate therapy will typically require chronic treatment.

Two different types of cells called osteoblasts and osteoclasts are involved in the bone formation and resorption processes, respectively. *See* H. Fleisch, *Bisphosphonates In Bone Disease, From The Laboratory To The Patient*, 3rd Edition, Parthenon Publishing (1997), which is incorporated by reference herein in its entirety. Osteoblasts are cells that are located on the bone surface. These cells secrete an osseous organic matrix, which then calcifies. Substances such as fluoride, parathyroid hormone, and certain cytokines such as protaglandins are known to provide a stimulatory effect on osetoblast cells. However, an aim of current research is to develop therapeutic agents that will selectively increase or stimulate the bone formation activity of the osteoblasts.

Osteoclasts are usually large multinucleated cells that are situated either on the surface of the cortical or trabecular bone or within the cortical bone. The osteoclasts resorb bone in a closed, sealed-off microenvironment located between the cell and the bone. The recruitment and activity of osteoclasts is known to be influenced by a series of cytokines and hormones. It is well known that bisphosphonates are selective inhibitors of osteoclastic bone resorption, making these compounds important therapeutic agents in the treatment or prevention of a variety of systemic or localized bone disorders caused by or associated with abnormal bone resorption. However, despite the utility of bisphosphonates there remains the desire amongst researchers to develop additional therapeutic agents for inhibiting the bone resorption activity of osteoclasts.

Prostaglandins such as the PGE_2 series are known to stimulate bone formation and increase bone mass in mammals, including man. It is believed that the four different receptor subtypes, designated EP_1, EP_2, EP_3, and EP_4 are involved in

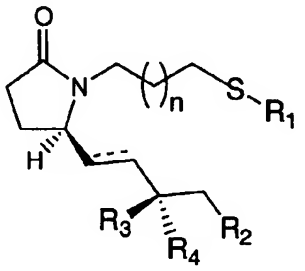
mediating the bone modeling and remodeling processes of the osteoblasts and osteoclasts. The major prostaglandin receptor in bone is EP_4, which is believed to provide its effect by signaling via cyclic AMP.

In present invention it is further found that the formula I agonists of the EP_4 subtype receptor are useful for stimulating bone formation.

SUMMARY OF THE INVENTION

This invention relates to potent selective agonists of the EP_4 subtype of prostaglandin E2 receptors, their use or a formulation thereof in the treatment of glaucoma and other conditions that are related to elevated intraocular pressure in the eye of a patient. Another aspect of this invention relates to the use of such compounds to provide a neuroprotective effect to the eye of mammalian species, particularly humans. This invention further relates to the use of the compounds of this invention for mediating the bone modeling and remodeling processes of the osteoblasts and osteoclasts.

More particularly, this invention relates to novel EP4 agonist having the structural formula I:



FORMULA I

or a pharmaceutically acceptable salt, enantiomer, diastereomer or mixture thereof:

wherein,

R_1 represents hydroxy, CN, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, C_{1-4} alkoxy, a group of the formula $-(CH_2)_nNR_6R_7$, or $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a;

R_6 and R_7 independently represents hydrogen, or C_{1-4} alkyl;

R_3 and R_4 independently represent hydrogen, C_{1-4} alkyl, C_{3-6} cycloalky, hydroxy, or C_{1-4} alkoxy;

R_2 represents C_{1-8} alkyl, C_{2-8} alkenyl, C_{2-8} alkynyl, C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, $(CH_2)_{0-8}$heteroaryl, $(CH_2)_{0-8}$ heterocycloalkyl, said alkyl, alkenyl, alkynyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a;

R_a represents hydrogen, C_{1-6} alkoxy, C_{1-6} alkyl, CF_3, nitro, amino, cyano, C_{1-6} alkylamino, or halogen;

The symbol --- is a double or single bond;

n represents 0-4; and

p represents 1-3.

This and other aspects of the invention will be realized upon inspection of the invention as a whole.

DETAILED DESCRIPTION OF THE INVENTION

The invention is described herein in detail using the terms defined below unless otherwise specified.

The term "therapeutically effective amount", as used herein, means that amount of the EP_4 receptor subtype agonist of formula I, or other actives of the present invention, that will elicit the desired therapeutic effect or response or provide the desired benefit when administered in accordance with the desired treatment regimen. A preferred therapeutically effective amount relating to the treatment of abnormal bone resorption is a bone formation, stimulating amount. Likewise, a preferred therapeutically effective amount relating to the treatment of ocular hypertension or glaucoma is an amount effective for reducing intraocular pressure and/or treating ocular hypertension and/or glaucoma.

"Pharmaceutically acceptable" as used herein, means generally suitable for administration to a mammal, including humans, from a toxicity or safety standpoint.

The term "alkyl" refers to a monovalent alkane (hydrocarbon) derived radical containing from 1 to 10 carbon atoms unless otherwise defined. It may be straight, branched or cyclic. Preferred alkyl groups include methyl, ethyl, propyl, isopropyl, butyl, t-butyl, cyclopentyl and cyclohexyl. When the alkyl group is said to be substituted with an alkyl group, this is used interchangeably with "branched alkyl group".

Cycloalkyl is a specie of alkyl containing from 3 to 15 carbon atoms, without alternating or resonating double bonds between carbon atoms. It may contain from 1 to 4 rings, which are fused. Examples of cycloalkyl groups are cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, and cycloheptyl.

Alkoxy refers to C_1-C_6 alkyl-O-, with the alkyl group optionally substituted as described herein. Examples of alkoxy groups are methoxy, ethoxy, propoxy, butoxy and isomeric groups thereof.

Alkenyl refers to alkyl groups having a double bond such as vinyl, propenyl, butenyl, pentenyl, hexenyl, heptenyl, octenyl and isomeric groups thereof.

Alkynyl refers to alkyl groups having a triple bond such as ethynyl, propynyl, butynyl, pentynyl, hexynyl, heptynyl, octynyl and isomeric groups thereof.

Halogen (halo) refers to chlorine, fluorine, iodine or bromine.

Aryl refers to aromatic rings e.g., phenyl, substituted phenyl and the like, as well as rings which are fused, e.g., naphthyl, phenanthrenyl and the like. An aryl group thus contains at least one ring having at least 6 atoms, with up to five such rings being present, containing up to 22 atoms therein, with alternating (resonating) double bonds between adjacent carbon atoms or suitable heteroatoms. The preferred aryl groups are phenyl, naphthyl and phenanthrenyl. Aryl groups may likewise be substituted as defined. Preferred substituted aryls include phenyl and naphthyl.

The term "heterocycloalkyl" refers to a cycloalkyl group (nonaromatic) having 3 to 10 carbon atoms in which one of the carbon atoms in the ring is replaced by a heteroatom selected from O, S or N, and in which up to three additional carbon atoms may be replaced by hetero atoms.

The term "heteroatom" means O, S or N, selected on an independent basis.

The term "heteroaryl" refers to a monocyclic aromatic hydrocarbon group having 5 or 6 ring atoms, or a bicyclic aromatic group having 8 to 10 atoms, containing at least one heteroatom, O, S or N, in which a carbon or nitrogen atom is the point of attachment, and in which one or two additional carbon atoms is optionally replaced by a heteroatom selected from O or S, and in which from 1 to 3 additional carbon atoms are optionally replaced by nitrogen heteroatoms, said heteroaryl group being optionally substituted as described herein. Examples of this type are pyrrole, pyridine, oxazole, thiazole, tetrazole, and oxazine. Additional nitrogen atoms may be present together with the first nitrogen and oxygen or sulfur, giving, e.g., thiadiazole.

The term "agonist" as used herein means EP4 subtype compounds of formula I interact with the EP4 receptor to produce maximal, super maximal or submaximal effects compared to the natural agonist, PGE2. See Goodman and Gilman, The Pharmacological Basis of Therapeutics, 9th edition, 1996, chapter 2.

Nonlimiting examples of bisphosphonate actives useful herein include the following:

Alendronic acid, 4-amino-1-hydroxybutylidene-1,1-bisphosphonic acid.

Alendronate (also known as alendronate sodium or alendronate monosodium trihydrate), 4-amino-1-hydroxybutylidene-1,1-bisphosphonic acid monosodium trihydrate.

Alendronic acid and alendronate are described in U.S. Patents 4,922,007, to Kieczykowski et al., issued May 1, 1990; 5,019,651, to Kieczykowski et al., issued May 28, 1991; 5,510,517, to Dauer et al., issued April 23, 1996; 5,648,491, to Dauer et al., issued July 15, 1997, all of which are incorporated by reference herein in their entirety.

Cycloheptylaminomethylene-1,1-bisphosphonic acid, YM 175, Yamanouchi (cimadronate), as described in U.S. Patent 4,970,335, to Isomura et al., issued November 13, 1990, which is incorporated by reference herein in its entirety.

1,1-dichloromethylene-1,1-diphosphonic acid (clodronic acid), and the disodium salt (clodronate, Procter and Gamble), are described in Belgium Patent 672,205 (1966) and *J. Org. Chem 32*, 4111 (1967), both of which are incorporated by reference herein in their entirety.

1-hydroxy-3-(1-pyrrolidinyl)-propylidene-1,1-bisphosphonic acid (EB-1053).

1-hydroxyethane-1,1-diphosphonic acid (etidronic acid).

1-hydroxy-3-(N-methyl-N-pentylamino)propylidene-1,1-bisphosphonic acid, also known as BM-210955, Boehringer-Mannheim (ibandronate), is described in U.S. Patent No. 4,927,814, issued May 22, 1990, which is incorporated by reference herein in its entirety.

6-amino-1-hydroxyhexylidene-1,1-bisphosphonic acid (neridronate).

3-(dimethylamino)-1-hydroxypropylidene-1,1-bisphosphonic acid (olpadronate).

3-amino-1-hydroxypropylidene-1,1-bisphosphonic acid (pamidronate).

[2-(2-pyridinyl)ethylidene]-1,1-bisphosphonic acid (piridronate) is described in U.S. Patent No. 4,761,406, which is incorporated by reference in its entirety.

1-hydroxy-2-(3-pyridinyl)-ethylidene-1,1-bisphosphonic acid (risedronate).

(4-chlorophenyl)thiomethane-1,1-disphosphonic acid (tiludronate) as described in U.S. Patent 4,876,248, to Breliere et al., October 24, 1989, which is incorporated by reference herein in its entirety.

1-hydroxy-2-(1H-imidazol-1-yl)ethylidene-1,1-bisphosphonic acid (zolendronate).

A non-limiting class of bisphosphonates useful in the instant invention are selected from the group consisting of alendronate, cimadronate, clodronate, tiludronate, etidronate, ibandronate, neridronate, olpandronate, risedronate, piridronate, pamidronate, zolendronate, pharmaceutically acceptable salts thereof, and mixtures thereof.

A non-limiting subclass of the above-mentioned class in the instant case is selected from the group consisting of alendronate, pharmaceutically acceptable salts thereof, and mixtures thereof.

A non-limiting example of the subclass is alendronate monosodium trihydrate.

One embodiment of this invention is realized when R_1 is CN, $(CH_2)_n$heteroaryl, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a and all other variables are as originally described. Note, when R_1 is O_2R_6, sulfur is hexavalent.

Another embodiment of this invention is realized when R_1 is $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a and all other variables are as originally described.

A sub-embodiment of this invention is realized when the heteroaryl is a tetrazole and all other variables are as originally described.

Still another embodiment of this invention is realized when R_2 is C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, or $(CH_2)_{0-8}$heteroaryl, said alkyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a, and all other variables are as originally described.

Yet another embodiment of this invention is realized when R_2 is $(CH_2)_{0-8}$aryl, or $(CH_2)_{0-8}$heteroaryl, said aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a, and all other variables are as originally described.

Preferred compounds of this invention are:

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(1-methyl-1*H*–tetrazol—5-yl)thio]butyl}pyrrolidin-2-one,

4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl thiocyanate,

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(1*H*–tetrazol-5-ylthio)butyl]pyrrolidin-2-one,

3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoic acid,

[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]methanesulfonic acid,

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylsulfonyl)butyl]-pyrrolidin-2-one,

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[1*H*-tetrazol-5-ylmethyl)thiobutyl}pyrrolidin-2-one, or

[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetic acid.

Another embodiment of this invention is directed to a composition containing an EP_4 agonist of Formula I and a pharmaceutically acceptable carrier.

Yet another embodiment of this invention is directed to a method for decreasing elevated intraocular pressure or treating glaucoma by administration,

preferably topical or intra-camaral administration, of a composition containing an EP_4 agonist of Formula I and optionally a pharmaceutically acceptable carrier.

This invention is further concerned with a process for making a pharmaceutical composition comprising a compound of formula I and a pharmaceutically acceptable carrier.

The claimed compounds bind strongly and act on PGE_2 receptor, particularly on the EP_4 subtype receptor and therefore are useful for preventing and/or treating glaucoma and ocular hypertension. Use of the compounds of formula I for the manufacture of a medicament for treating glaucoma and elevated intraocular pressure is also included.

Dry eye is a common ocular surface disease afflicting millions of people. Although it appears that dry eye may result from a number of unrelated pathogenic causes, the common end result is the breakdown of the tear film, which results in dehydration of the exposed outer surface of the eye. (Lemp, Report of the Nation Eye Institute/Industry Workshop on Clinical Trials in Dry Eyes, The *CLAO* Journel, 21(4):221-231 (1995)). One cause for dry eye is the decreased mucin production by the conjunctival cells and/or corneal epithelial cells of mucin, which protects and lubricates the ocular surface (Gipson and Inatomi, Mucin genes expressed by ocular surface epithelium. Progress in Retinal and Eye Research, 16:81-98 (1997)). Functional EP4 receptors have been found in human conjuctival epithelial cells (see US Patent 6,344,477, incorporated by reference in its entirey) and it is appreciated that both human corneal epithelial cells (Progess in Retinal and Eye Research, 16:81-98(1997)) and conjuctival cells (Dartt et al. Localization of nerves adjacent to goblet cells in rat conjucntiva. Current Eye Research, 14:993-1000 (1995)) are capable of secreting mucins. Thus, the compounds of formula I are useful for treating dry eye.

Macular edema is swelling within the retina within the critically important central visual zone at the posterior pole of the eye. An accumulation of fluid within the retina tends to detach the neural elements from one another and from their local blood supply, creating a dormancy of visual function in the area. It is believed that EP_4 agonist which lower IOP are useful for treating diseases of the macular such as macular edema or macular degeneration. Thus, another aspect of this invention is a method for treating macular edema or macular degeneration.

Glaucoma is characterized by progressive atrophy of the optic nerve

and is frequently associated with elevated intraocular pressure (IOP). It is possible to treat glaucoma, however, without necessarily affecting IOP by using drugs that impart a neuroprotective effect. See Arch. Ophthalmol. Vol. 112, Jan 1994, pp. 37-44; Investigative Ophthamol. & Visual Science, 32, 5, April 1991, pp. 1593-99. It is believed that EP4 agonist which lower IOP are useful for providing a neuroprotective effect. They are also believed to be effective for increasing retinal and optic nerve head blood velocity and increasing retinal and optic nerve oxygen by lowering IOP, which when coupled together benefits optic nerve health. As a result, this invention further relates to a method for increasing retinal and optic nerve head blood velocity, or increasing retinal and optic nerve oxygen tension or providing a neuroprotective effect or a combination thereof by using an EP4 agonist of formula I.

The compounds produced in the present invention are readily combined with suitable and known pharmaceutically acceptable excipients to produce compositions which may be administered to mammals, including humans, to achieve effective IOP lowering. Thus, this invention is also concerned with a method of treating ocular hypertension or glaucoma by administering to a patient in need thereof one of the compounds of formula I alone or in combination with a β-adrenergic blocking agent such as timolol, betaxolol, levobetaxolol, carteolol, levobunolol, a parasympathomimetic agent such as pilocarpine, a sympathomimetic agents such as epinephrine, iopidine, brimonidine, clonidine, para-aminoclonidine, a carbonic anhydrase inhibitor such as dorzolamide, acetazolamide, metazolamide or brinzolamide; a prostaglandin such as latanoprost, travaprost, unoprostone, rescula, S1033 (compounds set forth in US Patent Nos. 5,889,052; 5,296,504; 5,422,368; and 5,151,444); a hypotensive lipid such as lumigan and the compounds set forth in US Patent No. 5,352,708; a neuroprotectant disclosed in US Patent No. 4,690,931, particularly eliprodil and R-eliprodil as set forth in WO 94/13275, including memantine; or an agonist of 5-HT2 receptors as set forth in PCT/US00/31247, particularly 1-(2-aminopropyl)-3-methyl-1H-imdazol-6-ol fumarate and 2-(3-chloro-6-methoxy-indazol-1-yl)-1-methyl-ethylamine.

Thus, this invention is also concerned with a method for increasing retinal and optic nerve head blood velocity, or increasing retinal and optic nerve oxygen tension or providing a neuroprotective effect or a combination thereof by administering to a patient in need thereof one of the compounds of formula I alone or in combination with a β-adrenergic blocking agent such as timolol, betaxolol, levobetaxolol, carteolol, levobunolol, a parasympathomimetic agent such as

pilocarpine, a sympathomimetic agents such as epinephrine, iopidine, brimonidine, clonidine, para-aminoclonidine, a carbonic anhydrase inhibitor such as dorzolamide, acetazolamide, metazolamide or brinzolamide; a prostaglandin such as latanoprost, travaprost, unoprostone, rescula, S1033 (compounds set forth in US Patent Nos. 5,889,052; 5,296,504; 5,422,368; and 5,151,444); a hypotensive lipid such as lumigan and the compounds set forth in US Patent No. 5,352,708; a neuroprotectant disclosed in US Patent No. 4,690,931, particularly eliprodil and R-eliprodil as set forth in WO 94/13275, including memantine; or an agonist of 5-HT2 receptors as set forth in PCT/US00/31247, particularly 1-(2-aminopropyl)-3-methyl-1H-imdazol-6-ol fumarate and 2-(3-chloro-6-methoxy-indazol-1-yl)-1-methyl-ethylamine. Use of the compounds of formula I for the manufacture of a medicament for increasing retinal and optic nerve head blood velocity, or increasing retinal and optic nerve oxygen tension or providing a neuroprotective effect or a combination thereof is also included in this invention.

This invention is further concerned with a method for treating macular edema or macular degeneration by administering to a patient in need thereof one of the compounds of formula I alone or in combination with a β-adrenergic blocking agent such as timolol, betaxolol, levobetaxolol, carteolol, levobunolol, a parasympathomimetic agent such as pilocarpine, a sympathomimetic agents such as epinephrine, iopidine, brimonidine, clonidine, para-aminoclonidine, a carbonic anhydrase inhibitor such as dorzolamide, acetazolamide, metazolamide or brinzolamide; a prostaglandin such as latanoprost, travaprost, unoprostone, rescula, S1033 (compounds set forth in US Patent Nos. 5,889,052; 5,296,504; 5,422,368; and 5,151,444); a hypotensive lipid such as lumigan and the compounds set forth in US Patent No. 5,352,708; a neuroprotectant disclosed in US Patent No. 4,690,931, particularly eliprodil and R-eliprodil as set forth in WO 94/13275, including memantine; or an agonist of 5-HT2 receptors as set forth in PCT/US00/31247, particularly 1-(2-aminopropyl)-3-methyl-1H-imdazol-6-ol fumarate and 2-(3-chloro-6-methoxy-indazol-1-yl)-1-methyl-ethylamine. Use of the compounds of formula I for the manufacture of a medicament for treating macular edema or macular degeneration is also included.

The EP_4 agonist used in the instant invention can be administered in a therapeutically effective amount intravaneously, subcutaneously, topically, transdermally, parenterally or any other method known to those skilled in

the art. Ophthalmic pharmaceutical compositions are preferably adapted for topical administration to the eye in the form of solutions, suspensions, ointments, creams or as a solid insert. Ophthalmic formulations of this compound may contain from 0.001 to 5% and especially 0.001 to 0.1% of medicament. Higher dosages as, for example, up to about 10% or lower dosages can be employed provided the dose is effective in reducing intraocular pressure, treating glaucoma, increasing blood flow velocity or oxygen tension. For a single dose, from between 0.001 to 5.0 mg, preferably 0.005 to 2.0 mg, and especially 0.005 to 1.0 mg of the compound can be applied to the human eye.

The pharmaceutical preparation which contains the compound may be conveniently admixed with a non-toxic pharmaceutical organic carrier, or with a non-toxic pharmaceutical inorganic carrier. Typical of pharmaceutically acceptable carriers are, for example, water, mixtures of water and water-miscible solvents such as lower alkanols or aralkanols, vegetable oils, peanut oil, polyalkylene glycols, petroleum based jelly, ethyl cellulose, ethyl oleate, carboxymethyl-cellulose, polyvinylpyrrolidone, isopropyl myristate and other conventionally employed acceptable carriers. The pharmaceutical preparation may also contain non-toxic auxiliary substances such as emulsifying, preserving, wetting agents, bodying agents and the like, as for example, polyethylene glycols 200, 300, 400 and 600, carbowaxes 1,000, 1,500, 4,000, 6,000 and 10,000, antibacterial components such as quaternary ammonium compounds, phenylmercuric salts known to have cold sterilizing properties and which are non-injurious in use, thimerosal, methyl and propyl paraben, benzyl alcohol, phenyl ethanol, buffering ingredients such as sodium borate, sodium acetates, gluconate buffers, and other conventional ingredients such as sorbitan monolaurate, triethanolamine, oleate, polyoxyethylene sorbitan monopalmitylate, dioctyl sodium sulfosuccinate, monothioglycerol, thiosorbitol, ethylenediamine tetracetic acid, and the like. Additionally, suitable ophthalmic vehicles can be used as carrier media for the present purpose including conventional phosphate buffer vehicle systems, isotonic boric acid vehicles, isotonic sodium chloride vehicles, isotonic sodium borate vehicles and the like. The pharmaceutical preparation may also be in the form of a microparticle formulation. The pharmaceutical preparation may also be in the form of a solid insert. For example, one may use a solid water soluble polymer as the carrier for the medicament. The polymer used to form the insert may be any water soluble non-toxic polymer, for example, cellulose derivatives such as methylcellulose, sodium carboxymethyl cellulose, (hydroxyloweralkyl cellulose),

hydroxyethyl cellulose, hydroxypropyl cellulose, hydroxypropylmethyl cellulose; acrylates such as polyacrylic acid salts, ethylacrylates, polyactylamides; natural products such as gelatin, alginates, pectins, tragacanth, karaya, chondrus, agar, acacia; the starch derivatives such as starch acetate, hydroxymethyl starch ethers, hydroxypropyl starch, as well as other synthetic derivatives such as polyvinyl alcohol, polyvinyl pyrrolidone, polyvinyl methyl ether, polyethylene oxide, neutralized carbopol and xanthan gum, gellan gum, and mixtures of said polymer.

Suitable subjects for the administration of the formulation of the present invention include primates, man and other animals, particularly man and domesticated animals such as cats, rabbits and dogs.

The pharmaceutical preparation may contain non-toxic auxiliary substances such as antibacterial components which are non-injurious in use, for example, thimerosal, benzalkonium chloride, methyl and propyl paraben, benzyldodecinium bromide, benzyl alcohol, or phenylethanol; buffering ingredients such as sodium chloride, sodium borate, sodium acetate, sodium citrate, or gluconate buffers; and other conventional ingredients such as sorbitan monolaurate, triethanolamine, polyoxyethylene sorbitan monopalmitylate, ethylenediamine tetraacetic acid, and the like.

The ophthalmic solution or suspension may be administered as often as necessary to maintain an acceptable IOP level in the eye. It is contemplated that administration to the mammalian eye will be from once up to three times daily.

For topical ocular administration the novel formulations of this invention may take the form of solutions, gels, ointments, suspensions or solid inserts, formulated so that a unit dosage comprises a therapeutically effective amount of the active component or some multiple thereof in the case of a combination therapy.

The compounds of the instant invention are also useful for mediating the bone modeling and remodeling processes of the osteoblasts and osteoclasts. See PCT US99/23757 filed October 12, 1999 and incorporated herein by reference in its entirety. The major prostaglandin receptor in bone is EP_4, which is believed to provide its effect by signaling via cyclic AMP. See Ikeda T, Miyaura C, Ichikawa A, Narumiya S, Yoshiki S and Suda T 1995, *In situ localization of three subtypes (EP_1, EP_3 and EP_4) of prostaglandin E receptors in embryonic and newborn mice., J Bone Miner Res* **10** (sup 1):S172, which is incorporated by reference herein in its entirety..

Thus, another object of the present invention is to provide methods for stimulating bone formation, i.e. osteogenesis, in a mammal comprising administering to a mammal in need thereof a therapeutically effective amount of an EP_4 receptor subtype agonist of formula I. Use of the compounds of formula I for for stimulating bone formation is also included

Still another object of the present invention to provide methods for stimulating bone formation in a mammal in need thereof comprising administering to said mammal a therapeutically effective amount of an EP_4 receptor subtype agonist of formula I and a bisphosphonate active.

Yet another object of the present invention to provide pharmaceutical compositions comprising a therapeutically effective amount of an EP_4 receptor subtype agonist of formula I and a bisphosphonate active.

It is another object of the present invention to provide methods for treating or reducing the risk of contracting a disease state or condition related to abnormal bone resorption in a mammal in need of such treatment or prevention, comprising administering to said mammal a therapeutically effective amount of an EP_4 receptor subtype agonist of formula I.

The disease states or conditions related to abnormal bone resorption include, but are not limited to, osteoporosis, glucocorticoid induced osteoporosis, Paget's disease, abnormally increased bone turnover, periodontal disease, tooth loss, bone fractures, rheumatoid arthritis, periprosthetic osteolysis, osteogenesis imperfecta, metastatic bone disease, hypercalcemia of malignancy, and multiple myeloma.

Within the method comprising administering a therapeutically effective amount of an EP_4 receptor subtype agonist of formula I and a bisphosphonate active, both concurrent and sequential administration of the EP_4 receptor subtype agonist of formula I and the bisphosphonate active are deemed within the scope of the present invention. Generally, the formulations are prepared containing 5 or 10 mg of a bisphosphonate active, on a bisphosphonic acid active basis. With sequential administration, the agonist and the bisphosphonate can be administered in either order. In a subclass of sequential administration the agonist and bisphosphonate are typically administered within the same 24 hour period. In yet a further subclass, the agonist and bisphosphonate are typically administered within about 4 hours of each other.

In the present invention, as it relates to bone stimulation, the agonist is typically administered for a sufficient period of time until the desired therapeutic

effect is achieved. The term "until the desired therapeutic effect is achieved", as used herein, means that the therapeutic agent or agents are continuously administered, according to the dosing schedule chosen, up to the time that the clinical or medical effect sought for the disease or condition being mediated is observed by the clinician or researcher. For methods of treatment of the present invention, the compounds are continuously administered until the desired change in bone mass or structure is observed. In such instances, achieving an increase in bone mass or a replacement of abnormal bone structure with normal bone structure are the desired objectives. For methods of reducing the risk of a disease state or condition, the compounds are continuously administered for as long as necessary to prevent the undesired condition. In such instances, maintenance of bone mass density is often the objective.

Nonlimiting examples of administration periods can range from about 2 weeks to the remaining lifespan of the mammal. For humans, administration periods can range from about 2 weeks to the remaining lifespan of the human, preferably from about 2 weeks to about 20 years, more preferably from about 1 month to about 20 years, more preferably from about 6 months to about 10 years, and most preferably from about 1 year to about 10 years.

Regarding treatment of abnormal bone resorption and ocular disorders, the formula I agonists generally have an EC_{50} value from about 0.001 nM to about 100 microM, although agonists with activities outside this range can be useful depending upon the dosage and route of administration. In a subclass of the present invention, the agonists have an EC_{50} value of from about 0.01 microM to about 10 microM. In a further subclass of the present invention, the agonists have an EC_{50} value of from about 0.1 microM to about 10 microM. EC_{50} is a common measure of agonist activity well known to those of ordinary skill in the art and is defined as the concentration or dose of an agonist that is needed to produce half, i.e. 50%, of the maximal effect. See also, Goodman and Gilman's, *The Pharmacologic Basis of Therapeutics*, 9th edition, 1996, chapter 2, E. M. Ross, *Pharmacodynamics, Mechanisms of Drug Action and the Relationship Between Drug Concentration and Effect*, and PCT US99/23757, filed October 12, 1999, which are incoroporated by reference herein in their entirety.

The herein examples illustrate but do not limit the claimed invention. Each of the claimed compounds are EP_4 agonists and are useful for a number of physiological ocular and bone disorders.

The compounds of this invention can be made, with some modification, in accordance with US Patent No. 6,043,275, EP0855389 and WO 01/46140, all of which are incorporated herein by reference in their entirety. The following non-limiting examples, given by way of illustration, is demonstrative of the present invention.

Preparation 1

(5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-pyrrolidin-2-one

Step A: (5*R*)-(tert-butyl-dimethyl-silanyloxymethyl)-1-(4-chlorobutyl)pyrrolidin-2-one

To a solution of (5*R*)-(tert-butyl-dimethyl-silanyloxymethyl)-pyrrolidin-2-one (*Tetrahedron: Asymmetry*, **1996**, *7*, 2113) (2.83 g, 12.34 mmol) in 60 ml DMF was added NaH (95%, 325.7 mg, 13.57 mmol) in one portion and the mixture was heated at 50 °C for 30 min. Then 4-bromo-1-chlorobutane (2.96 g, 17.27 mmol) and a catalytic amount of nBu_4NI were added and the mixture was stirred at 50 °C for 1 h. The reaction was cooled to room temperature and water (100 ml) was added. The aqueous phase was extracted with AcOEt (4x200ml), the organic phases were washed with water (200 ml), brine (100 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent AcOEt 1: Hexanes 1) to provide (5*R*)-(tert-butyl-dimethyl-silanyloxymethyl)-1-(4-chlorobutyl)pyrrolidin-2-one as an oil. ^1H NMR ($CDCl_3$) 3.71-3.53 (m, 6H), 3.05 (m, 1H), 2.46-2.24 (m, 2H), 2.05 (m, 1H), 1.84-1.61 (m, 4H), 0.85 (s, 9H), 0.03 (s, 6H); MS 320.2-322.2 (M+1).

Step B: (5*R*)-1-(4-chlorobutyl)-5-(hydroxymethyl)pyrrolidin-2-one

To a solution of (5*R*)-(tert-butyl-dimethyl-silanyloxymethyl)-1-(4-chlorobutyl)pyrrolidin-2-one (1.95 g, 6.11 mmol) in CH_2Cl_2 (25 ml) in a Teflon Erlenmeyer at 0 °C was added dropwise HF-pyridine complex (1 ml), and the solution was allowed to reach room temperature, and was stirred for 1.5 h. Water (20 ml) and 1N HCl (1 ml) were added to the reaction mixture. The aqueous phase was extracted with CH_2Cl_2 (4x30ml), the organic phases was washed with brine (20 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 1: Toluene 1) to provide (5*R*)-1-(4-chlorobutyl)-5-(hydroxymethyl)pyrrolidin-2-one as

an oil. ^{1}H NMR ($CDCl_3$) 4.00 (s, 1H), 3.71-3.53 (m, 6H), 3.03 (m, 1H), 2.46-2.22 (m, 2H), 2.14-1.88 (m, 2H), 1.79-1.55 (m, 4H); MS 206.1-208.1 (M+1).

Step C: (2*R*)-1-(4-chlorobutyl)-5-oxopyrrolidine-2-carboxaldehyde

To a solution of (5*R*)-1-(4-chlorobutyl)-5-(hydroxymethyl)pyrrolidin-2-one (309.6 mg, 1.5 mmol) in CH_2Cl_2 (7 ml) was added Dess-Martin periodinane (638 mg, 1.5 mmol) portionwise over 40 min at room temperature. After 1 h, the solvent was removed under reduced pressure, and the residue triturated with Et_2O (3x5 ml), filtered on a celite plug, and the solvent removed. (2*R*)-1-(4-chlorobutyl)-5-oxopyrrolidine-2-carboxaldehyde was obtained as a colorless oil. ^{1}H NMR ($CDCl_3$) 9.58 (s, 1H), 4.18 (m, 1H), 3.65 (m, 1H), 3.53 (t, J = 8 Hz, 2H), 3.08 (m, 1H), 2.43 (m, 2H), 2.30(m, 1H), 2.08 (m, 1H), 1.78-1.56 (m, 4H).

Step D: (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-oxo-4-phenylbut-1-enyl]pyrrolidin-2-one

To a solution of (3-phenyl-2-oxo-propyl)-phosphonic acid dimethyl ester (938 mg, 4 mmol) in DME (20 ml) at 0 °C was added portionwise NaH 95 % (100.8 mg, 4.2 mmol), and the mixture was stirred 20 min at 0 °C. Then a solution of (2*R*)-1-(4-chlorobutyl)-5-oxopyrrolidine-2-carboxaldehyde in DME (5 ml) was added dropwise and the reaction mixture was allowed to reach room temperature, and stirred overnight. A half-saturated solution of NH_4Cl (10 ml) was added and the aqueous phase was extracted with AcOEt (4x60ml); the organic phases was washed with water (20 ml), brine (20 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 2: Toluene 8) to provide (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-oxo-4-phenylbut-1-enyl]pyrrolidin-2-one as an oil. ^{1}H NMR ($CDCl_3$) 7.35-7.20 (m, 5H), 6.64 (dd, J = 15.7 Hz, 8.2 Hz, 1H), 6.25 (d, J = 15.7 Hz, 1H), 4.17 (m, 1H), 3.85 (s, 2H), 3.55-3.50 (m, 3H), 2.77 (m, 1H), 2.43-2.17 (m, 3H), 1.81-1.75 (m, 1H), 1.70-1.51 (m, 4H).

Step E: (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]pyrrolidin-2-one

To a solution of (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-oxo-4-phenylbut-1-enyl]pyrrolidin-2-one (161 mg, 0.50 mmol) in MeOH (5 ml) at –20°C was added portionwise $NaBH_4$ (31 mg, 0.8 mmol). The mixture was stirred at –20°C for 1 h, and

the solvent was removed under reduced pressure. The residue was dissolved in a mixture of water (5 ml) and 1N HCl (1 ml), the aqueous phase was extracted with AcOEt (3x15ml); the organic phases was washed with water (5 ml), brine (5 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 4: Toluene 6) to provide both diastereoisomers of (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]pyrrolidin-2-one as an oil. ^{1}H NMR ($CDCl_3$) 7.36-7.22 (m, 5H), 5.78 (m, 1H), 5.51 (m, 1H), 4.44 (m, 1H), 4.07 (m, 1H), 3.59-3.45 (m, 3H), 2.95-2.77 (m, 3H), 2.44-2.19 (m, 3H), 2.43-2.17 (m, 3H), 1.70-1.55 (m, 5H).

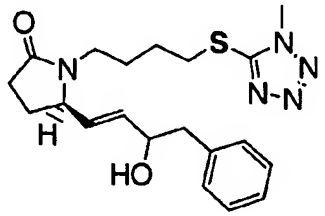
Preparation 2

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(triisopropylsilyl)thio]butyl}-pyrrolidin-2-one

To a solution of (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]pyrrolidin-2-one (273.9 mg, 0.852 mmol) in THF (5 ml) were added triisopropylsilylsulfide (324.4 mg, 1.70 mmol), a catalytic amount of nBu_4NI and portionwise NaH 95 % (30.7 mg, 1.28 mmol). The mixture was heated to 50°C for 1 h. The reaction was cooled to room temperature and water (2 ml) was added. The aqueous phase was extracted with AcOEt (4x10ml), the organic phases were washed with water (2 ml), brine (2 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent AcOEt 1: Hexanes 3) to provide both diastereoisomers of (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(triisopropylsilyl)thio]butyl}pyrrolidin-2-one as an oil. ^{1}H NMR ($CDCl_3$) 7.30-7.16 (m, 5H), 5.72 (m, 1H), 5.45 (m, 1H), 4.37 (m, 1H), 4.02 (m, 1H), 3.44 (m, 1H), 2.86-2.79 (m, 3H), 2.51 (m, 2H), 2.35-2.12 (m, 3H), 1.94 (s, 1H), 1.64-1.50 (m, 5H), 1.2 (m, 3H), 1.05 (d, J = 8.0 Hz, 18H); MS 476.4 (M+1).

EXAMPLE 1

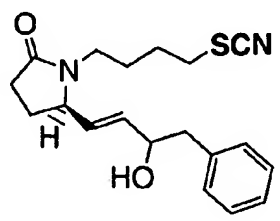
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(1-methyl-1*H* –tetrazol—5-yl)thio]butyl}pyrrolidin-2-one



To a solution of the (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]pyrrolidin-2-one (50.0 mg, 0.155 mmol) in DMF (0.5 ml) were added 5-mercapto-1-methyltetrazole sodium salt, and a catalytic amount of nBu_4NI. The mixture was heated to 50°C overnight. The reaction was cooled to room temperature and water (5 ml) was added. The aqueous phase was extracted with AcOEt (4x10ml), the organic phases were washed with water (2 ml), brine (2 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent AcOEt 2: Hexanes 3) to provide both diastereoisomers of (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(1-methyl-1*H* –tetrazol—5-yl) thio]butyl}pyrrolidin-2-one as an oil. ^1H NMR ($CDCl_3$) 7.30-7.18 (m, 5H), 5.74 (m, 1H), 5.44 (m, 1H), 4.41 (m, 1H), 4.01 (m, 1H), 3.90 (s, 3H), 3.46-3.27 (m, 3H), 2.93-2.82 (m, 3H), 2.74 (s, 0.6 H) and 2.65 (s, 0.4 H), 2.55-2.13 (m, 3H), 1.77-1.53 (m, 5H); MS 402.3 (M+1).

EXAMPLE 2

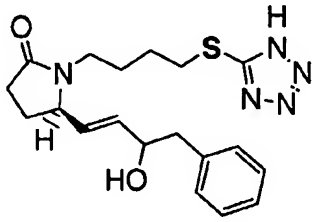
4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl thiocyanate



To a solution of the (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]pyrrolidin-2-one (50.0 mg, 0.155 mmol) in DMF (1 ml) were added potassium thiocyanate (150.7 mg, 1.55 mmol), and a catalytic amount of nBu_4NI. The mixture was heated to 50°C overnight. The reaction was cooled to room temperature and water (5 ml) was added. The aqueous phase was extracted with AcOEt (4x10ml), the organic phases were washed with water (2 ml), brine (2 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 4: Toluene 6) to provide both diastereoisomers of 4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl thiocyanate as an oil. ^1H NMR ($CDCl_3$) 7.35-7.22 (m, 5H), 5.78 (m, 1H), 5.46 (m, 1H), 4.43 (m, 1H), 4.04 (m, 1H), 3.46 (m, 1H), 3.04-2.84 (m, 5H), 2.41-2.19 (m, 3H), 2.06 (s, 0.6H) and 2.02 (s, 0.4H), 1.82-1.56 (m, 5H); MS 345.4 (M+1).

EXAMPLE 3

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(1*H* –tetrazol-5-ylthio)butyl]pyrrolidin-2-one

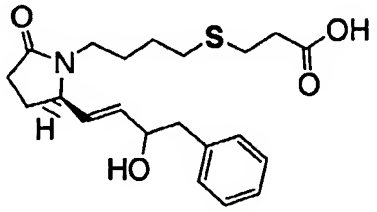


4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl thiocyanate (52.4 mg, 0.152 mmol) was mixed with tributylstanylazide (151.3 mg, 0.455 mmol), and the mixture was heated to 120°C for 3 h. The reaction was cooled to room temperature and a 5% KF solution (2 ml) and 1N HCl (1 ml) were added. The aqueous phase was extracted with AcOEt (4x10ml), the organic phases were washed with 5% KF (2x5 ml), brine (2 ml), dried on Na_2SO_4, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-

chromatography on silica gel (gradient CH_2Cl_2 : MeOH : AcOH (100:0:0) to (100:0:0.5) to (96:4:0.5) to (95:5:0.5)) to provide both diastereoisomers of (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(1*H* –tetrazol-5-ylthio)butyl]pyrrolidin-2-one as an oil. ^{1}H NMR ($CDCl_3$) 7.25-7.14 (m, 5H), 5.75 (m, 1H), 5.36 (m, 1H), 4.41 (m, 1H), 4.00 (m, 1H), 3.15 (m, 2H), 2.91-2.70 (m, 3H), 2.38-2.11 (m, 3H), 1.63-1.46 (m, 5H); MS 386.2 (M-1).

EXAMPLE 4

3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoic acid



Step A : methyl 3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoate

To a solution of the (5*R*)-1-(4-chlorobutyl)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]pyrrolidine-2-one (50.0 mg, 0.155 mmol) in DMF (0.8 ml) were added 3-mercaptopropanoic acid methyl ester (93.0 mg, 0.755 mmol), a catalytic amount of nBu_4NI and then dropwise 1M MeONa (0.62 ml, 0.62mmol). The mixture was heated to 80°C for 24h. The reaction was cooled to room temperature and water (6 ml) was added. The aqueous phase was extracted with AcOEt (4x10ml), the organic phases were washed with water (2 ml), brine (2 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 4: Toluene 6) to provide both diastereoisomers of methyl 3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoate as an oil. ^{1}H NMR ($CDCl_3$) 7.34-7.20 (m, 5H), 5.76 (m, 1H), 5.47 (m, 1H), 4.42 (m, 1H), 4.03 (m, 1H), 3.70 (s, 3H), 3.48 (m,

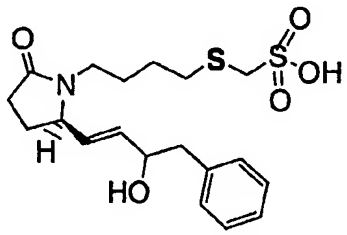
1H), 2.95-2.76 (m, 5H), 2.63-2.54 (m, 4H), 2.41-2.17 (m, 3H), 2.06 (s, 0.6H) and 2.02 (s, 0.4H), 1.78-1.50 (m, 5H) ; MS 406.7 (M+1).

Step B : 3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoic acid

To a solution of methyl 3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoate (19.6 mg, 0.0484 mmol) in MeOH/THF (1:1)(2 ml) was added a solution of 1N LiOH (0.051 ml, 0.051 mmol) at 0 °C. The reaction mixture was stirred overnight at room temperature. 0.5N HCl (4 ml) was added, the aqueous phase was extracted with CH_2Cl_2 (4x10ml), the organic phases were washed with brine (2 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (gradient CH_2Cl_2: MeOH: AcOH (100:0:0) to (95:5:0.5)) to provide both diastereoisomers of 3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoic acid as an oil. ^{1}H NMR ($CDCl_3$) 7.29-7.16 (m, 5H), 5.72 (m, 1H), 5.42 (m, 1H), 4.38 (m, 1H), 4.01 (m, 1H), 3.44 (m, 1H), 2.95-2.14 (m, 12H), 1.62-1.48 (m, 5H) ; MS 390.1 (M-1).

EXAMPLE 5

[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]methanesulfonic acid

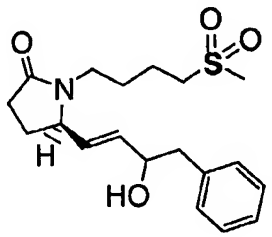


To a solution of the (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(triisopropylsilyl)thio]butyl}pyrrolidin-2-one (39.3 mg, 0.083 mmol) in THF (1 ml) were added sodium bromomethanesulfonate (32.6 mg, 0.165 mmol) and then dropwise 1M nBu_4NF (0.25 ml, 0.25mmol) The mixture was heated to 50°C for 1h.

The reaction was cooled to room temperature and 1N HCl (2 ml) was added. The aqueous phase was extracted with Et_2O (4x10ml), the organic phases were washed with 1N HCl (2 ml), brine (2 ml), dried on Na_2SO_4, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent CH_2Cl_2 95: MeOH 5:AcOH 0.5) to provide both diastereoisomers of methyl [4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]methanesulfonic acid as an oil. ^{1}H NMR ($CDCl_3$) 7.34-7.15 (m, 5H), 5.72 (m, 1H), 5.42 (m, 1H), 4.38 (m, 1H), 4.03 (m, 1H), 3.45 (m, 1H), 2.95-2.58 (m, 5H), 2.38-2.09 (m, 4H), 1.68-1.45 (m, 5H) ; MS 412.5 (M-1).

EXAMPLE 6

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylsulfonyl)butyl]-pyrrolidin-2-one



Step A : (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl[4-(methylthio)butyl]pyrrolidin-2-one

To a solution of the (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(triisopropylsilyl)thio]butyl}pyrrolidin-2-one (46.2 mg, 0.097 mmol) in THF (1 ml) were added methyliodide (17.6 mg, 0.126 mmol) and then dropwise 1M nBu_4NF (0.116 ml, 0.116mmol) at –78°C. The mixture was then stirred at room temperature for 1h. NH4Cl half saturated (2 ml) was added. The aqueous phase was extracted with AcOEt (5x8 ml), the organic phases were washed with brine (2 ml), dried on Na_2SO_4, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 4: Toluene 60) to provide (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylthio)butyl]pyrrolidin-2-one as an oil. ^{1}H NMR ($CDCl_3$) 7.29-7.16 (m, 5H),

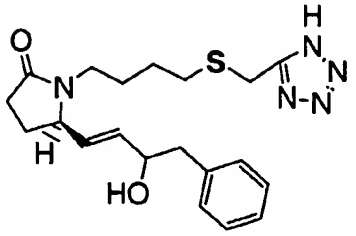
5.72 (m, 1H), 5.42 (m, 1H), 4.35 (m, 1H), 4.01 (m, 1H), 3.45 (m, 1H), 2.86-2.65 (m, 3H), 2.46 (m, 2H), 2.34-2.27 (m, 2H), 2.15-2.05 (m, 5H), 1.82-1.47 (m, 5H) ; MS 334.0 (M+1).

Step B: (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl[4-(methylsulfonyl)butyl]-pyrrolidin-2-one

To a solution of (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylthio)butyl]pyrrolidin-2-one (31.2 mg, 0.093 mmol) in CH_2Cl_2 : MeOH :H_2O (7:2:1)(5 ml) was added portionwise Oxone® (172.9 mg, 0.281 mmol) at 0°C. for 10 min., and 4 h at room temperature. 5% solution of $NaHSO_3$ (2 ml) was added. The aqueous phase was extracted with CH_2Cl_2 (4x10 ml), the organic phases were washed with water (5 ml), brine (2 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 7: Toluene 30) to provide (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylsulfonyl)butyl]pyrrolidin-2-one as an oil. ^{1}H NMR ($CDCl_3$) 7.28-7.15 (m, 5H), 5.72 (m, 1H), 5.40 (m, 1H), 4.35 (m, 1H), 3.96 (m, 1H), 3.33 (m, 1H), 3.07-2.96 (m, 2H), 2.86-2.79 (m, 5H), 2.36-2.11 (m, 4H), 1.81-1.54 (m, 5H) ; MS 366.0 (M+1).

EXAMPLE 7

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[1*H*-tetrazol-5-ylmethyl)thiobutyl}pyrrolidin-2-one



Step A: [(4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetonitrile

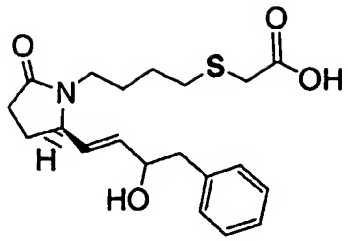
To a solution of the (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(triisopropylsilyl)thio]butyl}pyrrolidin-2-one (55.9 mg, 0.118 mmol) in THF (1 ml) were added bromoacetonitrile (21.2 mg, 0.177 mmol) and then dropwise 1M nBu_4NF (0.177 ml, 0.177mmol) at room temperature. The mixture was then heated at 50 °C. for 2 h. Water (2 ml) was added. The aqueous phase was extracted with AcOEt (4x10 ml), the organic phases were washed with water (2 ml), brine (2 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 4: Toluene 60) to provide [(4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetonitrile as an oil. ^1H NMR ($CDCl_3$) 7.34-7.21 (m, 5H), 5.78 (m, 1H), 5.45 (m, 1H), 4.42 (m, 1H), 4.05 (m, 1H), 3.51 (m, 1H), 3.31 (s, 2H), 2.93-2.71 (m, 5H), 2.48-2.19 (m, 4H), 2.11-1.57 (m, 5H) ; MS 359.0 (M+1).

Step B: (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[1*H*-tetrazol-5-ylmethyl)thiobutyl}pyrrolidin-2-one

[(4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetonitrile (39.8 mg, 0.111 mmol) was mixed with tributylstanylazide (110.7 mg, 0.333 mmol), and the mixture was heated to 120 C for 3 h. The reaction was cooled to room temperature and a 5% KF solution (2 ml) and 1N HCl (1 ml) were added. The aqueous phase was extracted with AcOEt (4x10ml), the organic phases were washed with 5% KF (2x5 ml), brine (2 ml), dried on Na_2SO_4, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (gradient CH_2Cl_2 : MeOH : AcOH (100:0:0) to (95:5:0.5)) to provide both diastereoisomers of (5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(1*H*-tetrazol-5-ylthio)butyl]pyrrolidin-2-one as an oil. ^1H NMR ($CDCl_3$) 7.26-7.15 (m, 5H), 5.75 (m, 1H), 5.37 (m, 1H), 4.42 (m, 1H), 4.00 (m, 1H), 3.90 (s, 2H), 3.30 (m, 1H), 2.90-2.65 (m, 3H), 2.53-2.13 (m, 5H), 1.68-1.32 (m, 5H) ; MS 400.2 (M-1).

EXAMPLE 8

[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetic acid



Step A: methyl ({[4-{(2*R*)-2-({[tert-butyl(dimethyl)silyl]oxy}methyl)-5-oxopyrrolidin-1-yl]butyl}thio)acetate

To a solution of (5*R*)-(tert-butyl-dimethyl-silanyloxymethyl)-pyrrolidin-2-one (*Tetrahedron: Asymmetry*, **1996**, *7*, 2113) (1.5 g, 6.55 mmol) in 30 ml DMF was added NaH 95% (173.0 mg, 7.20 mmol) in one portion and the mixture was heated at 50°C for 30 min. Then 4-bromo-1-chlorobutane (1.347 g, 7.86 mmol) and a catalytic amount of nBu_4NI were added and the mixture was stirred at 50 °C for 1 h. The reaction was cooled to room temperature and methyl thioglycolate (1.39 g, 13.1 mmol), then dropwise addition of 4.9N MeONa (2.4 ml, 11.79 mmol). The mixture was stirred overnight at room temperature and water (150 ml) was added. The aqueous phase was extracted with AcOEt (4x150ml), the organic phases were washed with water (200 ml), brine (100 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent AcOEt 1: Hexanes 1) to provide methyl ({[4-{(2*R*)-2-({[tert-butyl(dimethyl)silyl]oxy}methyl)-5-oxopyrrolidin-1-yl]butyl}thio)acetate as an oil. ^1H NMR ($CDCl_3$) 3.71-3.53 (m, 7H), 3.18 (s, 2H), 2.98 (m, 1H), 2.6 (m, 2H), 2.46-2.18 (m, 2H), 2.05 (m, 1H), 1.79 (m, 1H), 1.70-1.50 (m, 4H), 0.85 (s, 9H), 0.03 (s, 6H) ; MS 390.2 (M+1).

Step B: methyl ({4-[(2*R*)-2-(hydroxymethyl)-5-oxopyrrolidin-1-yl]butyl}thio)acetate

To a solution of methyl ({[4-{(2*R*)-2-({[tert-butyl(dimethyl)silyl]oxy}methyl)-5-oxopyrrolidin-1-yl]butyl}thio)acetate (571 mg, 1.47 mmol) in CH_2Cl_2 (8 ml) in a Teflon Erlenmeyer at 0°C was added dropwise HF-pyridine complex (0.8 ml), and the solution was allowed to reach room temperature, and was stirred for 1.5 h.. Water (20 ml) and 1N HCl (1 ml) were added to the reaction mixture. The aqueous phase was extracted with CH_2Cl_2 (4x30ml), the organic phases was washed with brine (20 ml), dried on $MgSO_4$, filtered and the

solvent was removed under reduced pressure to provide methyl ({4-[(2*R*)-2-(hydroxymethyl)-5-oxopyrrolidin-1-yl]butyl}thio)acetate as an oil. ^{1}H NMR ($CDCl_3$) 3.87-3.42 (m, 8H), 3.23 (s, 2H), 3.03 (m, 1H), 2.68 (d, J= 8.0 Hz, 2H), 2.60-2.32 (m, 2H), 2.20-1.92 (m, 2H), 1.79-1.55 (m, 4H) ; MS 276.2 (M+1).

Step C: Methyl ({4-[(2*R*)-2-formyl-5-oxopyrrolidin-1-yl]butyl}thio)acetate

To a solution of methyl ({4-[(2*R*)-2-(hydroxymethyl)-5-oxopyrrolidin-1-yl]butyl}thio)acetate (634.5 mg, 2.30 mmol) in CH_2Cl_2 (15 ml) was added Dess-Martin periodinane (975 mg, 1.5 mmol) portionwise over 40 min at room temperature. After 1 h, the solvent was removed under reduced pressure, and the residue triturated with Et_2O (3x5 ml), filtered on a Celite plug, and the solvent removed. Methyl ({4-[(2*R*)-2-formyl-5-oxopyrrolidin-1-yl]butyl}thio)acetate was obtained as a colorless oil. ^{1}H NMR ($CDCl_3$) 9.65 (s, 1H), 4.15 (m, 1H), 3.80-3.65 (m, 4H), 3.25 (s, 2H), 3.10 (m, 1H), 2.65 (m, 2H), 2.43 (m, 2H), 2.40-2.05(m, 2H), 1.78-1.56 (m, 4H).

Step D: methyl [(4-{(5*R*)-2-oxo-5-[(1*E*)-3-oxo-4-phenylbut-1-enyl]pyrrolidin-1-yl}butyl)thio]acetate

To a solution of (3-phenyl-2-oxo-propyl)-phosphonic acid dimethyl ester (264 mg, 1.09 mmol) in DME (5 ml) at 0°C was added portionwise NaH 95 % (26 mg, 1.09 mmol), and the mixture was stirred 20 min at 0°C. Then a solution of methyl ({4-[(2*R*)-2-formyl-5-oxopyrrolidin-1-yl]butyl}thio) (270 mg, 0.99 mmol) in DME (2 ml) was added dropwise and the reaction mixture was allowed to reach room temperature, and stirred overnight. A half-saturated solution of NH_4Cl (5 ml) was added and the aqueous phase was extracted with AcOEt (4x10ml); the organic phases was washed with water (10 ml), brine (10 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent AcOEt) to provide methyl [(4-{(5*R*)-2-oxo-5-[(1*E*)-3-oxo-4-phenylbut-1-enyl]pyrrolidin-1-yl}butyl)thio]acetate as an oil. ^{1}H NMR ($CDCl_3$) 7.40-7.20 (m, 5H), 6.65 (dd, J = 15.5 Hz, 8.1 Hz, 1H), 6.25 (d, J = 15.5 Hz, 1H), 4.18 (m, 1H), 3.88 (s, 2H), 3.75 (s, 3H), 3.55 (m, 1H), 3.22 (s, 2H),), 2.81-2.55 (m, 3H), 2.50-2.22 (m, 3H), 1.88-1.42 (m, 5H); MS 390.1 (M+1).

Step E: methyl [(4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-pyrrolidin-1-yl}butyl)thio]acetate

To a solution of methyl [(4-{(5*R*)-2-oxo-5-[(1*E*)-3-oxo-4-phenylbut-1-enyl]pyrrolidin-1-yl}butyl)thio]acetate (295.6 mg, 0.75 mmol) in MeOH (5 ml) at –20°C was added portionwise $NaBH_4$ (27.6 mg, 1.2 mmol). The mixture was stirred at –20°C for 1 h, and the solvent was removed under reduced pressure. The residue was dissolved in a mixture of water (5 ml) and 1N HCl (1 ml), the aqueous phase was extracted with AcOEt (3x15ml); the organic phases was washed with water (5 ml), brine (5 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (eluent Acetone 4: Toluene 6) to provide both diastereoisomers of methyl [(4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-pyrrolidin-1-yl}butyl)thio]acetate. ^1H NMR ($CDCl_3$) 7.37-7.21 (m, 5H), 5.70 (m, 1H), 5.50 (m, 1H), 4.44 (m, 1H), 4.08 (m, 1H), 3.75 (s, 3H), 2.98-2.62 (m, 6H), 2.55-2.19 (m, 3H), 2.43-2.17 (m, 3H), 1.80-1.52 (m, 5H). MS: 392.1 (M+1).

Step F: [4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetic acid

To a solution of methyl [(4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-pyrrolidin-1-yl}butyl)thio]acetate (90.0 mg, 0.23 mmol) in MeOH/THF (1:2)(5 ml) was added a solution of 1N LiOH (0.46 ml, 0.46 mmol) at 0°C. The reaction mixture was stirred 4 h at room temperature. 1N HCl (3 ml) was added, the aqueous phase was extracted with CH_2Cl_2 (4x10ml), the organic phases were washed with brine (2 ml), dried on $MgSO_4$, filtered and the solvent was removed under reduced pressure. The residual oil was purified by flash column-chromatography on silica gel (gradient CH_2Cl_2: MeOH: AcOH (100:0:0) to (94:6:0.5)) to provide both diastereoisomers of [4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]-acetic acid as an oil. ^1H NMR ($CDCl_3$) 7.35-7.16 (m, 5H), 5.77 (m, 1H), 5.42 (m, 1H), 4.42 (m, 1H), 4.05 (m, 1H), 3.44 (m, 1H), 3.20 (m, 2H), 2.95-2.42 (m, 5H), 2.95-2.14 (m, 5H), 1.62-1.48 (m, 5H); MS 376.3 (M-1).

I. Effects of an EF4 Agonist on Intraocular Pressure (IOP) in Rabbits and Monkeys.

Animals

Drug-naïve, male Dutch Belted rabbits and female cynomolgus monkeys are used in this study. Animal care and treatment in this investigation are in

compliance with guidelines by the National Institute of Health (NIH) and the Association for Research in Vision and Ophthalmology (ARVO) resolution in the use of animals for research. All experimental procedures str approved by the Institutional Animal Care and Use Committee of Merck and Company.

Drug Preparation and Administration

Drug concentrations are expressed in terms of the active ingredient (base). The compounds of this invention are dissolved in physiological saline at 0.01, 0.001, 0.0001 % for rabbit study and 0.05, 0.005% for monkey studies. Drug or vehicle aliquots (25 ul) are administered topically unilaterally or bilaterally. In unilateral applications, the contralateral eyes receive an equal volume of saline. Proparacaine (0.5%) is applied to the cornea prior to tonometry to minimize discomfort. Intraocular pressure (IOP) is recorded using a pneumatic tonometer (Alcon Applanation Pneumatonograph) or equivalent.

Statistical Analysis

The results are expressed as the changes in IOP from the basal level measured just prior to administration of drug or vehicle and represent the mean, plus or minus standard deviation. Statistical comparisons are made using the Student's t-test for non-paired data between responses of drug-treated and vehicle-treated animals and for paired data between ipsilateral and contralateral eyes at comparable time intervals. The significance of the date is also determined as the difference from the "t-0" value using Dunnett's "t" test. Asterisks represent a significance level of $p<0.05$.

A. Intraocular Pressure Measurement in Rabbits

Male Dutch Belted rabbits weighing 2.5-4.0 kg are maintained on a 12-hour light/dark cycle and rabbit chow. All experiments are performed at the same time of day to minimize variability related to diurnal rhythm. IOP is measured before treatment then the compounds of this invention or vehicle are instilled (one drop of 25 ul) into one or both eyes and IOP is measured at 30, 60, 120, 180, 240, 300, and 360 minutes after instillation. In some cases, equal number of animals treated bilaterally with vehicle only are evaluated and compared to drug treated animals as parallel controls.

B. Intraocular Pressure Measurements in Monkeys.

Unilateral ocular hypertension of the right eye is induced in female cynomolgus monkeys weighing between 2 and 3 kg by photocoagulation of the trabecular meshwork with an argon laser system (Coherent NOVUS 2000, Palo Alto, USA) using the method of Lee at al. (1985). The prolonged increase in intraocular pressure (IOP) results in changes to the optic nerve head that are similar to those found in glaucoma patients.

For IOP measurements, the monkeys are kept in a sitting position in restraint chairs for the duration of the experiment. Animals are lightly anesthetized by the intramuscular injection of ketamine hydrochloride (3-5 mg/kg) approximately five minutes before each IOP measurement and one drop of 0.5% proparacaine was instilled prior to recording IOP. IOP is measured using a pneumatic tonometer (Alcon Applanation Tonometer) or a Digilab pneumatonometer (Bio-Rad Ophthalmic Division, Cambridge, MA, USA).

IOP is measured before treatment and generally at 30, 60, 124, 180, 300, and 360 minutes after treatment. Baseline values are also obtained at these time points generally two or three days prior to treatment. Treatment consists of instilling one drop of 25 ul of the compounds of this invention (0.05 and 0.005 %) or vehicle (saline). At least one-week washout period is employed before testing on the same animal. The normotensive (contralateral to the hypertensive) eye is treated in an exactly similar manner to the hypertensive eye. IOP measurements for both eyes are compared to the corresponding baseline values at the same time point. Results are expressed as mean plus-or-minus standard deviation in mm Hg. The activity range of the compounds of this invention for ocular use is between 0.01 and 100,000 nM

II. Radioligand binding assays:

The assays used to test these compounds were performed essentially as described in: Abramovitz M, Adam M, Boie Y, Carriere M, Denis D, Godbout C, Lamontagne S, Rochette C, Sawyer N, Tremblay NM, Belley M, Gallant M, Dufresne C, Gareau Y, Ruel R, Juteau H, Labelle M, Ouimet N, Metters KM. The utilization of recombinant prostanoid receptors to determine the affinities and selectivities of prostaglandins and related analogs. Biochim Biophys Acta 2000 Jan 17;1483(2):285-293 and discussed below:

Stable expression of prostanoid receptors in the human embryonic kidney (HEK) 293(EBNA) cell line

Prostanoid receptor (PG) cDNAs corresponding to full length coding sequences were subcloned into the appropriate sites of the mammalian expression vector pCEP4 (Invitrogen) pCEP4PG plasmid DNA was prepared using the Qiagen plasmid preparation kit (QIAGEN) and transfected into HEK 293(EBNA) cells using LipofectAMINE@ (GIBCO-BRL) according to the manufacturers' instructions. HEK 293(EBNA) cells expressing the cDNA together with the hygromycin resistance gene were selected in Dulbecco's Modified Eagle Medium (DMEM) supplemented with 10 % heat inactivated fetal bovine serum, 1 mM sodium pyruvate, 100 U/ml Penicillin-G, 100 μg/ml Streptomycin sulphate, 250 μg/ml active GENETICIN™ (G418) (all from Life Technologies, Inc./BRL) and 200 μg/ml hygromycin (Calbiochem). Individual colonies were isolated after 2-3 weeks of growth under selection using the cloning ring method and subsequently expanded into clonal cell lines. Expression of the receptor cDNA was assessed by receptor binding assays.

HEK 293(EBNA) cells were grown in supplemented DMEM complete medium at 37°C in a humidified atmosphere of 6 % CO_2 in air, then harvested and membranes prepared by differential centrifugation (1000 x g for 10 min, then 160,000 x g for 30 min, all at 4°C) following lysis of the cells by nitrogen cavitation at 800 psi for 30 min on ice in the presence of protease inhibitors (2 mM phenylmethylsulfonylfluoride, 10 μM E-64, 100 μM leupeptin and 0.05 mg/ml pepstatin). The 160,000 x g pellets were resuspended in 10 mM HEPES/KOH (pH 7.4) containing 1 mM EDTA at approximately 5-10 mg/ml protein by Dounce homogenisation (Dounce A; 10 strokes), frozen in liquid nitrogen and stored at -80°C.

Prostanoid receptor binding assays

Prostanoid receptor binding assays were performed in a final incubation volume of 0.2 ml in 10 mM MES/KOH (pH 6.0) (EP subtypes, FP and TP) or 10 mM HEPES/KOH (pH 7.4) (DP and IP), containing 1 mM EDTA, 10 mM $MgCl_2$ (EP subtypes) or 10 mM $MnCl_2$ (DP, FP, IP and TP) and radioligand [0.5-1.0 nM [^{3}H]PGE_2 (181 Ci/mmol) for EP subtypes, 0.7 nM [^{3}H]PGD_2 (115 Ci/mmol) for DP, 0.95 nM [^{3}H]$PGF_{2\alpha}$ (170 Ci/mmol) for FP, 5 nM [^{3}H]iloprost (16 Ci/mmol) for IP and 1.8 nM [^{3}H]SQ 29548 (46 Ci/mmol) for TP]. EP_3 assays also contained 100 μM GTPγS. The reaction was initiated by addition of membrane protein (approximately 30 μg for EP_1, 20 μg for EP_2, 2 μg for EP_3, 10 μg for EP_4, 60 μg for FP, 30 μg for DP, 10 μg for IP and 10 μg for TP) from the 160,000 x g fraction. Ligands were added in dimethylsulfoxide (Me_2SO) which was kept constant at 1 %

(v/v) in all incubations. Non-specific binding was determined in the presence of 1 μM of the corresponding non-radioactive prostanoid. Incubations were conducted for 60 min (EP subtypes, FP and IP) or 30 min (DP and TP) at 30°C (EP subtypes, DP, FP and TP) or room temperature (IP) and terminated by rapid filtration through a 96-well Unifilter GF/C (Canberra Packard) prewetted in assay incubation buffer without EDTA (at 4°C) and using a Tomtec Mach III 96-well semi-automated cell harvester. The filters were washed with 3-4 ml of the same buffer, dried for 90 min at 55°C and the residual radioactivity bound to the individual filters determined by scintillation counting with addition of 50 μl of Ultima Gold F (Canberra Packard) using a 1450 MicroBeta (Wallac). Specific binding was calculated by subtracting non-specific binding from total binding. Specific binding represented 90-95 % of the total binding and was linear with respect to the concentrations of radioligand and protein used. Total binding represented 5-10 % of the radioligand added to the incubation media.

The activity range of the compounds of this invention for bone use is between 0.01 and 100,000 nM.

Bone Resorption Assays:

1. Animal Procedures:

For mRNA localization experiments, 5-week old Sprague-Dawley rats (Charles River) are euthanized by CO_2, their tibiae and calvariae are excised, cleaned of soft tissues and frozen immediately in liquid nitrogen. For EP_4 regulation experiments, 6-week old rats are given a single injection of either vehicle (7% ethanol in sterile water) or an anabolic dose of PGE_2 (Cayman Chemical, Ann Arbor, MI), 3-6 mg/kg in the same vehicle) intraperitoneally. Animals are euthanized at several time points post-injection and their tibiae and calvariae, as well as samples from lung and kidney tissues are frozen in liquid nitrogen.

2. Cell Cultures

RP-1 periosteal cells are spontaneously immortalized from primary cultures of periosteal cells from tibae of 4-week old Sprague-Dawley rats and are cultured in DMEM (BRL, Gaithersburg, MD) with 10 % fetal bovine serum (JRH Biosciences, Lenexa, KS). These cells do not express osteoblastic phenotypic markers in early culture, but upon confluence, express type I collagen, alkaline phosphatase and osteocalcin and produce mineralized extracellular matrix.

RCT-1 and RCT-3 are clonal cell lines immortalized by SV-40 large T antigen from cells released from fetal rat calvair by a cmbination collagenase/hyaluronidase digestion. RCT-1 cells, derived from cells released during the first 10 minutes of digestion (fraction I), are cultured in RPMI 1640 medium (BRL) with 10% fetal bovine serum and 0.4 mg/ml G418 (BRL). These cells differentiate and express osteoblastic features upon retinoic acid treatment. RCT-3 cells, immortalized from osteoblast-enriched fraction III cells, are cultured in F-12 medium (BRL) with 5% Fetal bovine serum and 0.4 mg/ml G418. TRAB-11 cells are also immortalized by SV40 large T antigen from adult rat tibia and are cultured in RPMI 1640 medium with 10% FBS and 0.4 mg/ml G418. ROS 17/2.8 rat osteosarcoma cells are cultured in F-12 containing 5% FBS. Osteoblast-enriched (fraction III) primary fetal rat calvaria cells are obtained by collagenase/hyaluronidase digestion of calvariae of 19 day-old rat fetuses. See Rodan et al., *Growth stimulation of rat calvaria osteoblastic cells by acidic FGF, Endocrinology,* 121, 1919-1923 (1987), which is incorporated by reference herein in its entirety. Cells are released during 30-50 minutes digestion (fraction III) and are cultured in F-12 medium containing 5% FBS.

P815 (mouse mastocytoma) cells, cultured in Eagles MEM with 10% FBS, and NRK (normal rat kidney fibroblasts) cells, cultured in DMEM with 10% FBS, are used as positive and negative controls for the expression of EP_4, respectively. See Abramovitz et al., *Human prostanoid receptors: cloning and characterization. In: Samulesson B. et al.* ed) *Advances in prostaglandin, Thromboszne and leukotriene research,* vol. 23, pp. 499-504 (1995) and de Larco et al., *Epithelioid and fibroblastic rat kidney cell clones: EGF receptors and the effect of mouse sarcoma virus transformation, Cell Physiol.*, 94, 335-342 (1978), which are both incorporated by reference herein in their entirety.

3. Northern Blot Analysis:

Total RNA is extracted from the tibial metaphysis or diaphysis and calvaria using a guanidinium isothiocyanate-phenol-chloroform method after pulverizing frozen bone samples by a tissue homogenizer. *See* P. Chomczynski et al., *Single-step method of RNA isolation by acid guanidium thiocyanate-phenol-chloroform extraction., Analyt Biochem*, 162, 156-159 (1987), which is incorporated by reference herein in its entirety. RNA samples (20 mg) are separated on 0.9% agarose/formaldehyde gels and transferred onto nylon membranes (Boehringer

Mannheim, Germany). Membranes are prehybridized in Hybrisol I (Oncor, Gaithersburg, MD) and 0.5 mg/ml sonicated salmon sperm DNA (Boehringer) at 42°C for 3 hours and are hybridized at 42°C with rat EP_2 and mouse EP_4 cDNA probes labeled with [^{32}P]-dCTP (Amersham, Buckinghamshire, UK) by random priming using the rediprime kit (Amersham). After hybridization, membranes are washed 4 times in 2xSSC + 0.1% SDS at room temperature for a total of 1 hour and once with 0.2xSSC + 0.1% SDS at 55°C for 1 hour and then exposed to Kodak XAR 2 film at -70°C using intensifying screens. After developing the films, bound probes are removed twice with 0.1% SDS at 80°C and membranes are hybridized with a human GAPDH (Glyceraldehyde 3-Phosphate Dehydrogenase) cDNA probe (purchased from Clontech, Palo Alto, CA) for loading control.

4. In-Situ Hybridization:

Frozen tibiae are sectioned coronally at 7 mm thickness and sections are mounted on charged slides (Probe On Plus, Fisher Scientific, Springfield, NJ) and are kept at -70°C until hybridization. cRNA probes are labeled with ^{35}S-UTPgS (ICN, Costa Mesa, CA) using a Riboprobe II kit (Promega Madison, WI). Hybridization is performed overnight at 50° C. *See M. Weinreb et al., Different pattern of alkaline phosphatase, osteopontin and osteocalcin expression in developing rat bone visualized by in-situ hybridization, J. Bone Miner Res.*, 5, 831-842 (1990) and D. Shinar et al., *Expression of alphav and beta3 integrin subunits in rat osteoclasts in situ, J. Bone Miner. Res.*, 8, 403-414 (1993), which are both incorporated by reference herein in their entirety. Following hybridization and washing, sections are dipped in Ilford K5 emulsion diluted 2:1 with 6% glycerol in water at 42° C and exposed in darkness at 4° C for 12-14 days. Slides are developed in Kodak D-19 diluted 1:1 with water at 15°, fixed, washed in distilled water and mounted with glycerol-gelatin (Sigma) after hematoxylin staining. Stained sections are viewed under the microscope (Olympus, Hamburg, Germany), using either bright-field or dark-field optics.

5. Expression Of EP_4 In Osteoblastic Cell Lines And In Bone Tissue.

The expression of EP_4 and EP_2 mRNA is examined in various bone derived cells including osteoblast-enriched primary rat calvaria cells, immortalized osteoblastic cell lines from fetal rat calvaria or from adult rat tibia and an osteoblastic

osteosarcoma cell line. Most of the osteoblastic cells and cell lines show significant amounts of 3.8 kb EP_4 mRNA, except for the rat osteosarcoma cell line ROS 17/2.8. Consistent with this finding, in ROS 17/2.8 cells PGE_2 has no effect on intracellular cAMP, which is markedly induced in RCT-3 and TRAB-11 cells. Treatment of RCT-1 cells with retinoic acid, which promotes their differentiation, reduces the levels of EP_4 mRNA. NRK fibroblasts do not express EP_4 mRNA, while P815 mastocytoma cells, used as positive controls, express large amounts of EP_4 mRNA. In contrast to EP_4 mRNA, none of the osteoblastic cells and cell lines express detectable amounts of EP_2 mRA in total RNA samples. Expression of EP_4 mRNA in osteoblastic cells, EP_4 is also expressed in total RNA isolated from tibiae and calvariae of 5-week-old rats. In contrast, no EP_2 mRNA is found in RNA from tibial shafts.

6. PGE_2 Induces The Expression Of EP_4 mRNA in RP-1 Periosteal Cells And In Adult Rat Tibiae

PGE_2 enhances its own production via upregulation of cyclooxygenase 2 expression in osteoblasts and in bone tissue thus autoamplifying its own effects. PGE_2 also increases the levels of EP_4 mRNA. RP-1 cells are immortalized from a primary culture of adult rat tibia periosteum is examined. These cells express osteoblast phenotypic markers upon confluence and form mineralized bone matrix when implanted in nude mice. Similar to the other osteoblastic cells examined, RP-1 periosteal cells express a 3.8 kb EP_4 transcript. Treatment with PGE_2 (10^{-6} M) rapidly increases EP_4 mRNA levels peaking at 2 hours after treatment. PGE_2 has no effect on EP_4 mRNA levels in the more differentiated RCT-3 cells pointing to cell-type specific regulation of EP_4 expression by PGE_2. EP_2 mRNA is not expressed in RP-1 cells before or after treatment with PGE_2.

To examine if PGE_2 regulates EP_4 mRNA levels *in vivo* in bone tissue, five-week-old male rats are injected with PGE_2 (3 - 6 mg/Kg). Systemic administration of PGE_2 rapidly increased EP_4 mRNA levels in the tibial diaphysis peaking at 2 h after injection. A similar effect of PGE_2 on EP_4 mRNA is observed in the tibial metaphysis and in calvaria. PGE_2 induces EP_4 mRNA levels *in vitro* in osteogenic periosteal cells and *in vivo* in bone tissue in a cell type-specific and tissue-specific manner. PGE_2 does not induce EP_2 mRNA in RP-1 cells nor in bone tissue.

7. Localization of EP_4 mRNA expression in bone tissue

In situ hybridization is used in order to localize cells expressing EP_4 in bone. In control experiment (vehicle-injected) rats, low expression of EP_4 is detected in bone marrow cells. Administration of a single anabolic dose of PGE_2 increased the expression of EP_4 in bone marrow cells. The distribution of silver grains over the bone marrow is not uniform and occurs in clumps or patches in many areas of the metaphysis. Within the tibial metaphysis, EP_4 expression is restricted to the secondary spongiosa area and is not seen in the primary spongiosa. Hybridization of similar sections with a sense probe (negative control) does not show any signal.

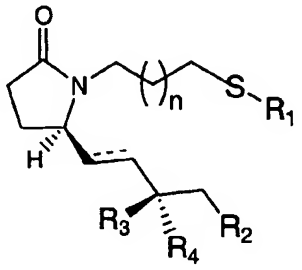
EP_4 is expressed in osteoblastic cells *in vitro* and in bone marrow cells *in vivo*, and is upregulated by its ligand, PGE_2.

8. Agonists Of the Present Invention

Using standard methods for measuring agonist activity, the following compounds are evaluated in cell cultures and in EP_4 receptor cell-free systems to determine the agonist activity of the compounds in terms of their EC_{50} value.

WHAT IS CLAIMED IS:

1. A compound having the structural formula I:



FORMULA I

or a pharmaceutically acceptable salt, enantiomer, diastereomer or mixture thereof:

wherein,

R_1 represents hydroxy, CN, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, C_{1-4} alkoxy, a group of the formula $-(CH_2)_nNR_6R_7$, or $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a;

R_6 and R_7 independently represents hydrogen, or C_{1-4} alkyl;

R_3 and R_4 independently represent hydrogen, C_{1-4} alkyl, C_{3-6} cycloalkyl, hydroxy, or C_{1-4} alkoxy;

R_2 represents C_{1-8} alkyl, C_{2-8} alkenyl, C_{2-8} alkynyl, C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, $(CH_2)_{0-8}$heteroaryl, $(CH_2)_{0-8}$ heterocycloalkyl, said alkyl, alkenyl, alkynyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a;

R_a represents hydrogen, C_{1-6} alkoxy, C_{1-6} alkyl, CF_3, nitro, amino, cyano, C_{1-6} alkylamino, or halogen;

The symbol --- is a double or single bond;

n represents 0-4; and

p represents 1-3.

2. A compound in accordance with claim 1 wherein R_1 is CN, $(CH_2)_n$heteroaryl, $(CH_2)_pCO_2R_6$, O_2R_6, or $(CH_2)_nSO_3R_6$, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a and all other variables are as originally described.

3. A compound in accordance with claim 2 wherein R_1 is $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a and all other variables are as originally described.

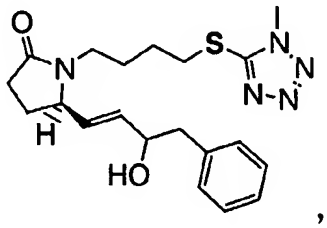
4. A compound in accordance with claim 3 wherein the heteroaryl is a tetrazole and all other variables are as originally described.

5. A compound in accordance with claim 1 wherein R_2 is C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, or $(CH_2)_{0-8}$heteroaryl, said alkyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a, and all other variables are as originally described.

6. A compound in accordance with claim 5 wherein R_2 is $(CH_2)_{0-8}$aryl, or $(CH_2)_{0-8}$heteroaryl, said aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a, and all other variables are as originally described.

7. A compound which is:

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(1-methyl-1*H*-tetrazol—5-yl)thio]butyl}pyrrolidin-2-one



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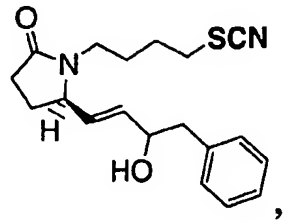
4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl thiocyanate



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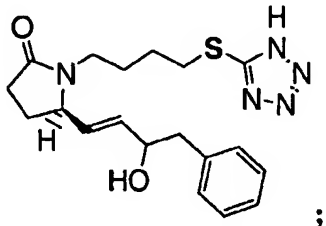
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(1*H*–tetrazol-5-ylthio)butyl]pyrrolidin-2-one



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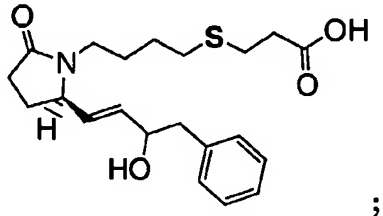
3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoic acid



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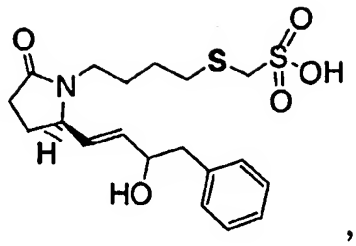
[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]methanesulfonic acid



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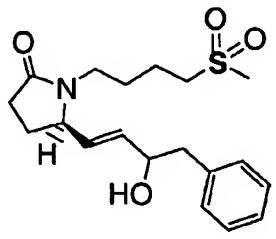
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylsulfonyl)butyl]-pyrrolidin-2-one



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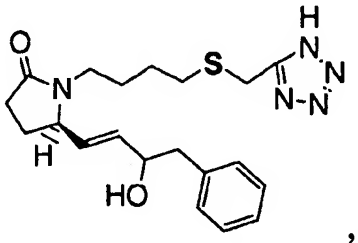
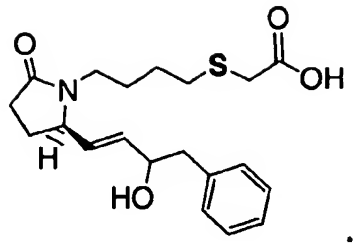
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[1*H*-tetrazol-5-ylmethyl)thiobutyl}pyrrolidin-2-one

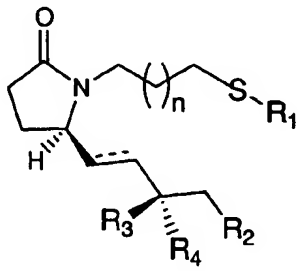


, or

[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetic acid



8. A method for treating ocular hypertension or glaucoma comprising administration to a patient in need of such treatment a therapeutically effective amount of a compound of formula I,



FORMULA I

or a pharmaceutically acceptable salt, enantiomer, diastereomer or mixture thereof:

wherein,

R_1 represents hydroxy, CN, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, C_{1-4} alkoxy, a group of the formula $-(CH_2)_nNR_6R_7$, or $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a;

R_6 and R_7 independently represents hydrogen, or C_{1-4} alkyl;

R_3 and R_4 independently represent hydrogen, C_{1-4} alkyl, hydroxy, or C_{1-4} alkoxy;

R_2 represents C_{1-8} alkyl, C_{2-8} alkenyl, C_{2-8} alkynyl, C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, $(CH_2)_{0-8}$heteroaryl, $(CH_2)_{0-8}$

heterocycloalkyl, said alkyl, alkenyl, alkynyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a;

R_a represents hydrogen, C_{1-6} alkoxy, C_{1-6} alkyl, CF_3, nitro, amino, cyano, C_{1-6} alkylamino, or halogen;

The symbol --- is a double or single bond;

n represents 0-4; and

p represents 1-3.

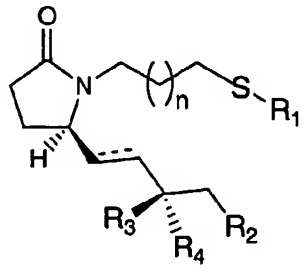
9. A method in accordance with claim 8 wherein the compound is:
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(1-methyl-1*H* –tetrazol—5-yl)thio]butyl}pyrrolidin-2-one,
4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl thiocyanate,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(1*H* –tetrazol-5-ylthio)butyl]pyrrolidin-2-one,
3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoic acid,
[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]methanesulfonic acid,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylsulfonyl)butyl]-pyrrolidin-2-one,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[1*H*-tetrazol-5-ylmethyl)thiobutyl}pyrrolidin-2-one, or
[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetic acid.

10. A method according to claim 8 wherein the topical formulation is a solution or suspension.

11. A method according to claim 8 wherein an active ingredient belonging to the group consisting of: β-adrenergic blocking agent, parasympathomimetic agent, sympathomimetic agent, carbonic anhydrase inhibitor, and a prostaglandin, hypotensive lipid, neuroprotectant, and 5-HT2 receptor agonist is added to the formulation.

12. A method according to claim 11 wherein the β-adrenergic blocking agent is timolol, betaxolol, levobetaxolol, carteolol, or levobunolol; the parasympathomimetic agent is pilocarpine; the sympathomimetic agent is epinephrine, brimonidine, iopidine, clonidine, or para-aminoclonidine, the carbonic anhydrase inhibitor is dorzolamide, acetazolamide, metazolamide or brinzolamide; the prostaglandin is latanoprost, travaprost, unoprostone, rescula, or S1033, the hypotensive lipid is lumigan, the neuroprotectant is eliprodil, R-eliprodil or memantine; and the 5-HT2 receptor agonist is 1-(2-aminopropyl)-3-methyl-1H-imdazol-6-ol fumarate or 2-(3-chloro-6-methoxy-indazol-1-yl)-1-methyl-ethylamine.

13. A method for treating macular edema or macular degeneration comprising administration to a patient in need of such treatment a pharmaceutically effective amount of a compound of formula I,



FORMULA I

or a pharmaceutically acceptable salt, enantiomer, diastereomer or mixture thereof:

wherein,

R_1 represents hydroxy, CN, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, C_{1-4} alkoxy, a group of the formula $-(CH_2)_nNR_6R_7$, or $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a;

R_6 and R_7 independently represents hydrogen, or C_{1-4} alkyl;

R_3 and R_4 independently represent hydrogen, C_{1-4} alkyl, hydroxy, or C_{1-4} alkoxy;

R_2 represents C_{1-8} alkyl, C_{2-8} alkenyl, C_{2-8} alkynyl, C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, $(CH_2)_{0-8}$heteroaryl, $(CH_2)_{0-8}$ heterocycloalkyl, said alkyl, alkenyl, alkynyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a;

R_a represents hydrogen, C_{1-6} alkoxy, C_{1-6} alkyl, CF_3, nitro, amino, cyano, C_{1-6} alkylamino, or halogen;

The symbol --- is a double or single bond;

n represents 0-4; and

p represents 1-3.

14. The method according to Claim 13 wherein the compound of formula I is applied as a topical formulation and an active ingredient belonging to the group consisting of β-adrenergic blocking agent, parasympatho-mimetic agent, sympathomimetic agent, carbonic anhydrase inhibitor, and a prostaglandin, hypotensive lipid, neuroprotectant, and 5-HT2 receptor agonist is added to the formulation.

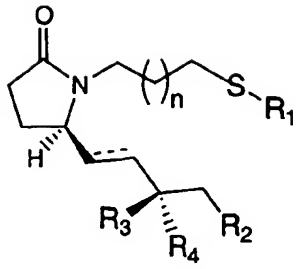
15. A method according to claim 14 wherein the the β-adrenergic blocking agent is timolol, betaxolol, levobetaxolol, carteolol, or levobunolol; the parasympathomimetic agent is pilocarpine; the sympathomimetic agent is epinephrine brimonidine, iopidine, clonidine, or para-aminoclonidine, the carbonic anhydrase

inhibitor is dorzolamide, acetazolamide, metazolamide or brinzolamide; the prostaglandin is latanoprost, travaprost, unoprostone, rescula, or S1033, the hypotensive lipid is lumigan, the neuroprotectant is eliprodil, R-eliprodil or memantine; and the 5-HT2 receptor agonist is 1-(2-aminopropyl)-3-methyl-1H-imdazol-6-ol fumarate or 2-(3-chloro-6-methoxy-indazol-1-yl)-1-methyl-ethylamine.

16. A method according to claim 15 wherein the compound is:

(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(1-methyl-1*H* –tetrazol—5-yl)thio]butyl}pyrrolidin-2-one,
4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl thiocyanate,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(1*H* –tetrazol-5-ylthio)butyl]pyrrolidin-2-one,
3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoic acid,
[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]methanesulfonic acid,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylsulfonyl)butyl]-pyrrolidin-2-one,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[1*H*-tetrazol-5-ylmethyl)thiobutyl}pyrrolidin-2-one, or
[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetic acid.

17. A method for increasing retinal and optic nerve head blood velocity, increasing retinal and optic nerve oxygen tension or providing a neuroprotective comprising administration to a patient in need of such treatment an effective ocular hypertensive formulation containing a compound of formula I :



FORMULA I

or a pharmaceutically acceptable salt, enantiomer, diastereomer or mixture thereof:

wherein,

R_1 represents hydroxy, CN, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, C_{1-4} alkoxy, a group of the formula $-(CH_2)_nNR_6R_7$, or $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a;

R_6 and R_7 independently represents hydrogen, or C_{1-4} alkyl;

R_3 and R_4 independently represent hydrogen, C_{1-4} alkyl, hydroxy, or C_{1-4} alkoxy;

R_2 represents C_{1-8} alkyl, C_{2-8} alkenyl, C_{2-8} alkynyl, C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, $(CH_2)_{0-8}$heteroaryl, $(CH_2)_{0-8}$ heterocycloalkyl, said alkyl, alkenyl, alkynyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a;

R_a represents hydrogen, C_{1-6} alkoxy, C_{1-6} alkyl, CF_3, nitro, amino, cyano, C_{1-6} alkylamino, or halogen;

The symbol --- is a double or single bond;

n represents 0-4; and

p represents 1-3.

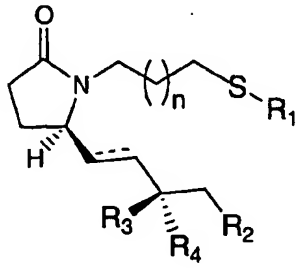
18. The method according to Claim 17 wherein the compound of formula I is applied as a topical formulation and an active ingredient belonging to the group consisting of β-adrenergic blocking agent, parasympatho-mimetic agent, sympathomimetic agent, carbonic anhydrase inhibitor, and a prostaglandin, hypotensive lipid, neuroprotectant, and 5-HT2 receptor agonist is added to the formulation.

19. A method according to claim 18 wherein the β-adrenergic blocking agent is timolol, betaxolol, levobetaxolol, carteolol, or levobunolol; the parasympathomimetic agent is pilocarpine; the sympathomimetic agent is epinephrine, brimonidine, iopidine, clonidine, or para-aminoclonidine, the carbonic anhydrase inhibitor is dorzolamide, acetazolamide, metazolamide or brinzolamide; the prostaglandin is latanoprost, travaprost, unoprostone, rescula, or S1033, the hypotensive lipid is lumigan, the neuroprotectant is eliprodil, R-eliprodil or memantine; and the 5-HT2 receptor agonist is 1-(2-aminopropyl)-3-methyl-1H-imdazol-6-ol fumarate or 2-(3-chloro-6-methoxy-indazol-1-yl)-1-methyl-ethylamine.

20. A method according to claim 19 wherein the compound is:
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[(1-methyl-1*H*–tetrazol—5-yl)thio]butyl}pyrrolidin-2-one,
4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl thiocyanate,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(1*H*–tetrazol-5-ylthio)butyl]pyrrolidin-2-one,
3-[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]propanoic acid,
[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]methanesulfonic acid,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-[4-(methylsulfonyl)butyl]-pyrrolidin-2-one,
(5*R*)-5-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-1-{4-[1*H*-tetrazol-5-ylmethyl)thiobutyl}pyrrolidin-2-one, or
[4-{(2*R*)-2-[(1*E*)-3-hydroxy-4-phenylbut-1-enyl]-5-oxopyrrolidin-1-yl}butyl)thio]acetic acid.

21. A method according to claim 2 in which the topical formulation optionally contains xanthan gum or gellan gum.

22. A method for stimulating bone formation in a mammal in need thereof comprising administering to said mammal a therapeutically effective amount of a compound of formula I,



FORMULA I

or a pharmaceutically acceptable salt, enantiomer, diastereomer or mixture thereof:

wherein,

R_1 represents hydroxy, CN, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, C_{1-4} alkoxy, a group of the formula $-(CH_2)_nNR_6R_7$, or $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a;

R_6 and R_7 independently represents hydrogen, or C_{1-4} alkyl;

R_3 and R_4 independently represent hydrogen, C_{1-4} alkyl, hydroxy, or C_{1-4} alkoxy;

R_2 represents C_{1-8} alkyl, C_{2-8} alkenyl, C_{2-8} alkynyl, C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, $(CH_2)_{0-8}$heteroaryl, $(CH_2)_{0-8}$ heterocycloalkyl, said alkyl, alkenyl, alkynyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a;

R_a represents hydrogen, C_{1-6} alkoxy, C_{1-6} alkyl, CF_3, nitro, amino, cyano, C_{1-6} alkylamino, or halogen;

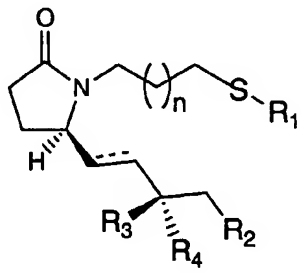
The symbol --- is a double or single bond;

n represents 0-4; and

p represents 1-3.

23. A method for treating or reducing the risk of contracting a disease state or condition related to abnormal bone resorption in a mammal in need of such treatment or prevention, comprising administering to said mammal a therapeutically effective amount of an EP_4 receptor subtype agonist of formula I:

the structural formula I:



FORMULA I

or a pharmaceutically acceptable salt, enantiomer, diastereomer or mixture thereof:

wherein,

R_1 represents hydroxy, CN, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, C_{1-4} alkoxy, a group of the formula $-(CH_2)_nNR_6R_7$, or $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a;

R_6 and R_7 independently represents hydrogen, or C_{1-4} alkyl;

R_3 and R_4 independently represent hydrogen, C_{1-4} alkyl, hydroxy, or C_{1-4} alkoxy;

R_2 represents C_{1-8} alkyl, C_{2-8} alkenyl, C_{2-8} alkynyl, C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, $(CH_2)_{0-8}$heteroaryl, $(CH_2)_{0-8}$ heterocycloalkyl, said alkyl, alkenyl, alkynyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a;

R_a represents hydrogen, C_{1-6} alkoxy, C_{1-6} alkyl, CF_3, nitro, amino, cyano, C_{1-6} alkylamino, or halogen;

The symbol --- is a double or single bond;

n represents 0-4; and

p represents 1-3.

24. A method according to claim 23 wherein said disease state or condition is selected from the group consisting of osteoporosis, glucocorticoid induced osteoporosis, Paget's disease, abnormally increased bone turnover, periodontal disease, tooth loss, bone fractures, rheumatoid arthritis, periprosthetic osteolysis, osteogenesis imperfecta, metastatic bone disease, hypercalcemia of malignancy, and multiple myeloma.

25. A method according to claim 24 wherein the disease state or condition is osteoporosis, glucocorticoid induced osteroporosis, or periodontal disease.

26. A method according to claim 22 which additionally contains a bisphosphonate active.

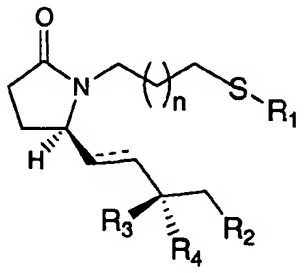
27. A method according to Claim 26 wherein said bisphosphonate active is selected from the group consisting of alendronate, cimadronate, clodronate, tiludronate, etidronate, ibandronate, neridronate, olpandronate, risedronate,

piridronate, pamidronate, zolendronate, pharmaceutically acceptable salts thereof, and mixtures thereof.

28. A method according to Claim 27 wherein said bisphosphonate is alendronate, pharmaceutically acceptable salts thereof, and mixtures thereof.

29. A pharmaceutical composition comprising a pharmaceutically acceptable carrier and a compound of formula I, as recited in claim 1.

30. A method for treating dry eye in mammals comprising administering to said mammal a therapeutically effective amount of an EP_4 receptor subtype agonist of formula I:



FORMULA I

or a pharmaceutically acceptable salt, enantiomer, diastereomer or mixture thereof:

wherein,

R_1 represents hydroxy, CN, $(CH_2)_pCO_2R_6$, O_2R_6, $(CH_2)_nSO_3R_6$, C_{1-4} alkoxy, a group of the formula $-(CH_2)_nNR_6R_7$, or $(CH_2)_n$heteroaryl, said heteroaryl unsubstituted or substituted with 1 to 3 groups of R_a;

R_6 and R_7 independently represents hydrogen, or C_{1-4} alkyl;

R_3 and R_4 independently represent hydrogen, C_{1-4} alkyl, hydroxy, or C_{1-4} alkoxy;

R_2 represents C_{1-8} alkyl, C_{2-8} alkenyl, C_{2-8} alkynyl, C_{2-8} alkenylaryl, C_{2-8} alkynylaryl, C_{3-7} cycloalkyl, $(CH_2)_{0-8}$aryl, $(CH_2)_{0-8}$heteroaryl, $(CH_2)_{0-8}$ heterocycloalkyl, said alkyl, alkenyl, alkynyl, aryl or heteroaryl unsubstituted or substituted with 1-3 groups of R_a;

R_a represents hydrogen, C_{1-6} alkoxy, C_{1-6} alkyl, CF_3, nitro, amino, cyano, C_{1-6} alkylamino, or halogen;

The symbol --- is a double or single bond;

n represents 0-4; and

p represents 1-3.

31. A method according to claim 30 wherein the administration to the eye is topical.

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(74) Common Representative: **MERCK & CO., INC.**; 126 East Lincoln Avenue, Rahway, NJ 07065-0907 (US).

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WO 03/047417 A3

(54) Title: EP4 RECEPTOR AGONIST, COMPOSITIONS AND METHODS THEREOF

(57) Abstract: This invention relates to potent selective agonists of the EP_4 subtype of prostaglandin E2 receptors, their use or a formulation thereof in the treatment of glaucoma and other conditions which are related to elevated intraocular pressure in the eye of a patient. This invention further relates to the use of the compounds of this invention for mediating the bone modeling and remodeling processes of the osteoblasts and osteoclasts.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/38039

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : A61K 31/4015; C07D 207/26
US CL : 548/551; 514/424

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
STN

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US2001/004715 A1 (CAMERON et el) 29 November 2001, see entire document.	1-30

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Date of the actual completion of the international search	Date of mailing of the international search report
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